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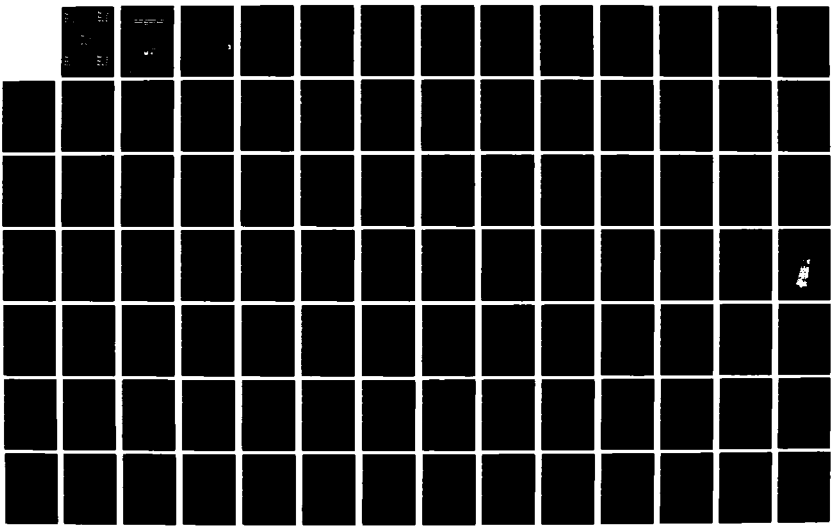

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Flat Plate Photovoltaic Power Systems: Description, Design, and Cost

by
Michael R. Hall
Garyl D. Smith
NWC Energy Program Office
David L. Holmes
Naval Civil Engineering Laboratory
Port Hueneme, Calif.

JULY 1982

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA 93555

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(U) The Energy Program Office at the Naval Weapons Center has been tasked to manage the Department of the Navy's photovoltaic effort. This effort includes participation in the Federal Photovoltaic Utilization Program (FPUP), which is sponsored by the Department of Energy, and encouragement of worldwide Navy activities to use Navy funds to procure cost-effective photovoltaic power systems.

(U) This report describes in simple nontechnical terms what photovoltaic power systems are, how they are sized, their costs, and their advantages and disadvantages. It also includes all tables and information necessary for the nontechnical person to determine preliminary sizes and costs of photovoltaic power systems for most applications. Navy activities can identify cost-effective applications for photovoltaic power systems by using this report and can procure the systems on their own or seek assistance from the Energy Program Office. The Energy Program Office will assist in preparing procurement specifications, evaluating proposals, awarding and monitoring contracts, and acceptance-testing the systems.

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INTRODUCTION

The Naval Weapons Center (NWC) has been involved in photovoltaic development since 1974 and was designated lead laboratory for the Department of the Navy's photovoltaic program in December 1978. Initial effort as lead laboratory was to coordinate the Navy's participation in the Federal Photovoltaic Utilization Program (FPUP) and to transfer the emerging photovoltaic technology from the research and development area to the user community. The goal of the Navy photovoltaic program is to use photovoltaic systems where they are cost-effective. In order to reach this goal, it is necessary to have the support of Navy activities.

This report serves as a guide to identify applications suitable for photovoltaic systems as a power source. In addition, the report contains information to assist the design engineer in preparing a preliminary system design and in determining the cost-effectiveness of the overall system.

The goal of the FPUP, a program funded by the Department of Energy (DOE), is to stimulate the photovoltaic industry by creating a demand for photovoltaic power systems. By creating the demand, DOE anticipates that the cost of photovoltaic power will be reduced so that applications will become cost-effective enough to keep up the demand. As the demand increases for photovoltaic power, the costs will decrease. Costs have been reduced under FPUP, and as they are reduced, more and more cost-effective applications are being identified.

FPUP, a multiyear program, is almost complete. No more applications are being accepted for funding under FPUP, and it is now time for the Navy to purchase photovoltaic power systems with Navy funds. The Navy photovoltaic program has developed skills in the procurement and installation of photovoltaic power systems under FPUP. NWC will continue to use its skills by assisting any Navy activity that wishes to procure a photovoltaic power system in preparing contract specifications, evaluating proposals, awarding and monitoring contracts, and acceptance-testing the systems. Assistance can be obtained by calling Michael Hall on AUTOVON 437-3411, extension 241, or commercial (619) 939-3411, extension 241.

PHOTOVOLTAIC POWER SYSTEM DESCRIPTION

The major elements of a photovoltaic power system for a stand-alone (nonutility-grid-connected) application are solar array modules, either concentrating or flat plate; rechargeable batteries; and a voltage regulator. For loads requiring an alternating current (AC), an inverter is required to convert the photovoltaic-generated direct-current (DC) power to AC power.

There are several types of concentrator solar arrays, and they all require either one- or two-axis sun-tracking mechanisms. The concentrator solar cell geometry is designed with multiple grid patterns to reduce the high cell losses that develop when the cell is subjected to high solar intensities. In addition, the cell temperature must not exceed 140°C. The cell temperature is controlled by mounting the solar cell on a pipe through which a coolant is circulated at a controlled rate to remove excess heat. A design used on passive concentrator collectors employs metal fins for heat rejection.

Flat plate modules have been widely used throughout the world during the last 10 years. Flat plate solar collectors do not require sun-tracking mechanisms. The collectors are oriented at a fixed tilt angle at the time of installation. To optimize performance, simple seasonal adjustment is made in the tilt angle.

Due to the extensive past experience, reliability, and simplicity of design, this report is concerned only with flat plate modules for stand-alone photovoltaic power systems. Figure 1 depicts a typical photovoltaic system using a flat plate solar array.

A photovoltaic power system captures solar radiation, converts it directly to DC electricity, conditions the DC electricity to supply the application load with the required power (e.g., 115 VAC, 60 Hz), and stores any excess power for use on cloudy days or at night.

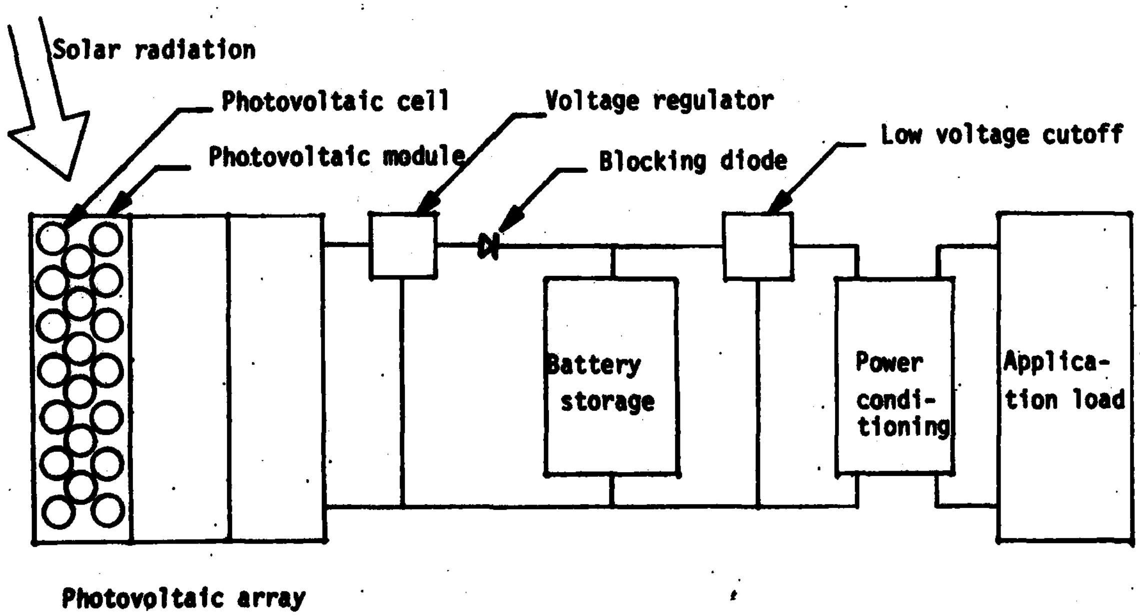

FIGURE 1. Photovoltaic Power System.

Photovoltaic Cell .

The photovoltaic cell, also known as a solar cell, is the power source for the system. The cell, which converts solar radiation directly into electricity, is made of a semiconducting material with chemical additives used to produce a pn junction near the surface of the material. Solar radiation reaches the earth in discrete amounts of pure energy called photons. When the photons hit the pn junction near the surface of the material, the photon's energy is used to produce a positive and a negative charge. The charges would recombine if it were not for the pn junction, which acts as a barrier and keeps the charges apart. The positive charges collect on the p-side of the junction and the negative charges collect on the n-side, creating a voltage potential across the junction. When electrical contacts are added to the p-side and n-side of the solar cell, this separation of charges can be used to supply power to an external load. The photovoltaic cell can be considered a "solar battery." Like a battery, the cell has positive and negative terminals and will supply power when connected to an external load. Unlike a battery, the cell cannot store energy, but only supplies energy when exposed to solar energy. The cell is, in effect, a constant-voltage DC generator. Figure 2 shows the construction and operation of a photovoltaic cell.

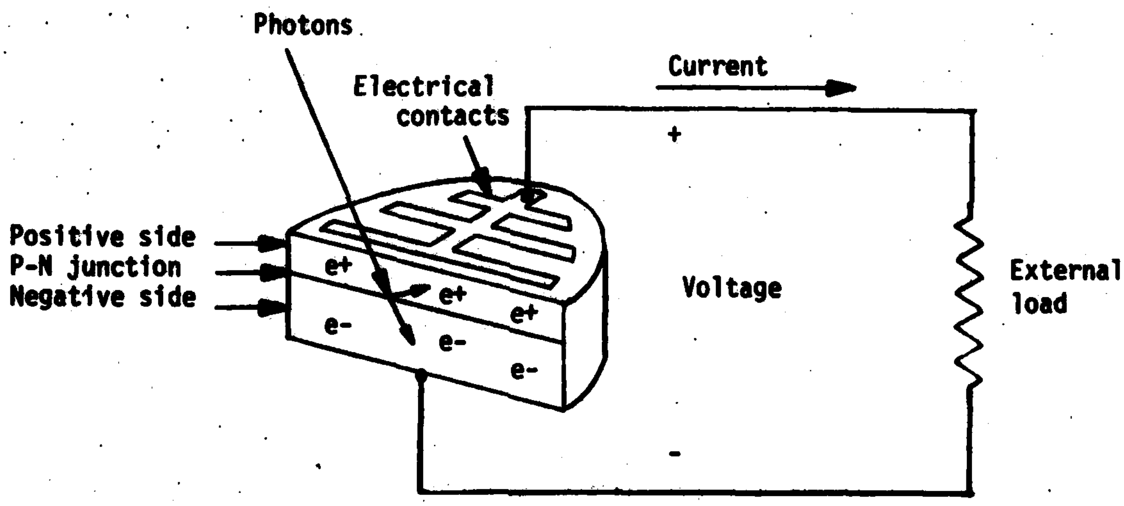

FIGURE 2. Construction and Operation of a Photovoltaic Cell.

The most common and commercially available photovoltaic cells are fabricated from single-crystal silicon ingots grown from semiconductor-grade polycrystalline silicon. The polycrystalline material is melted (together with controlled amounts of impurities) in a quartz crucible and grown from small "seed" crystals that are inserted into the melt and rotated as they are slowly withdrawn from the melt. Typically ingots 3 or 4 inches in diameter and 12 inches in length are grown by this process. The completed ingot is then sliced into wafers that are 10 to 15 mils thick. The wafers are chemically treated to remove defects. The pn junction is normally formed by gaseous diffusion of phosphorous. Electrical contacts are placed on the front and back side of the cell by a variety of techniques, including silk screening and evaporation of silver or other materials.

The photovoltaic cell current is primarily dependent on the amount of solar radiation striking the cell and the exposed cell area. The voltage produced is primarily dependent on the cell temperature. To compare photovoltaic cells from different manufacturers, it is necessary to state the different cell output characteristics under standard conditions of solar radiation and temperature. The photovoltaic industry has agreed to use the following conditions as Standard Test Conditions:

solar radiation striking the cell = 100 mW/cm^2 = 1 kW/m^2(317 Btu/h °F)

cell operating temperature = approximately 27 °C (80 °F)

Figure 3 shows the typical output of a 3-inch-diameter silicon solar cell under Standard Test Conditions. The cell output is also shown normalized to indicate at what operating point the maximum power is supplied by the cell.

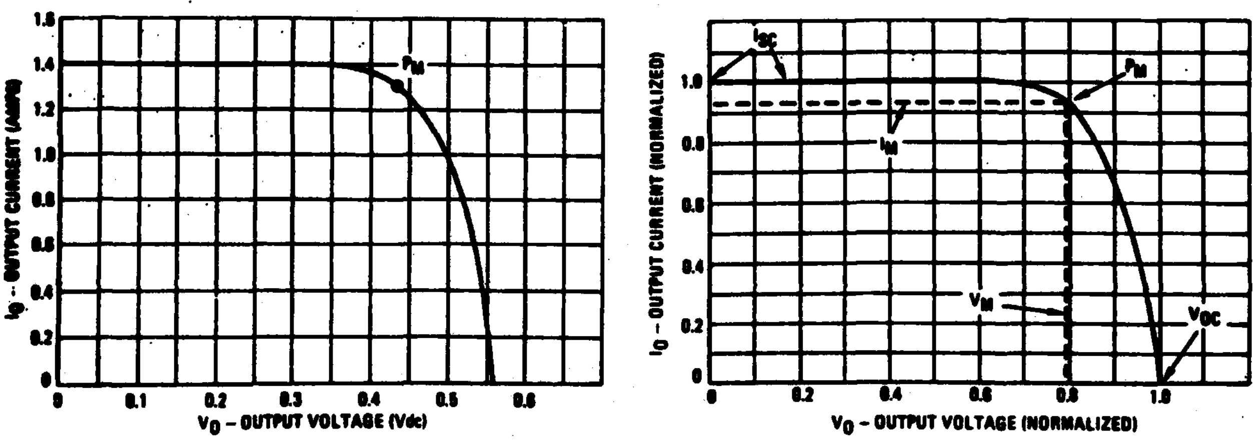

FIGURE 3. Typical 3-Inch Silicon Photovoltaic Cell Characteristic Curves.

When the cell's electrical contacts are shorted, the output voltage is zero, and the cell supplies the maximum amount of current physically possible. This is the short circuit current (I_{SC}). When the electrical contacts are opened, the cell will be forced to provide the highest voltage possible. This is the open circuit voltage (V_{OC}). The operating voltage, current, and power (power = volts × amperes) supplied by the cell to an external load will depend on the external load's electrical resistance. The photovoltaic cell's operating point will lie on the characteristic curve, and the cell will supply the maximum power to the load at the maximum power point (P_M) on the characteristic curve. The maximum power will be supplied when the load voltage is approximately 80% of the open circuit voltage. Figure 4 shows how the short circuit current, open circuit voltage, and maximum power point change with varying solar radiation intensities and cell temperatures.

As stated earlier, the photovoltaic cell acts like a battery because the cells can be connected in series to increase system output voltage or in parallel to increase system output current (Figure 5). When photovoltaic cells are connected in series, their output current is the same as for a single cell. When cells are connected in parallel, their output voltage is the same as for a single cell.

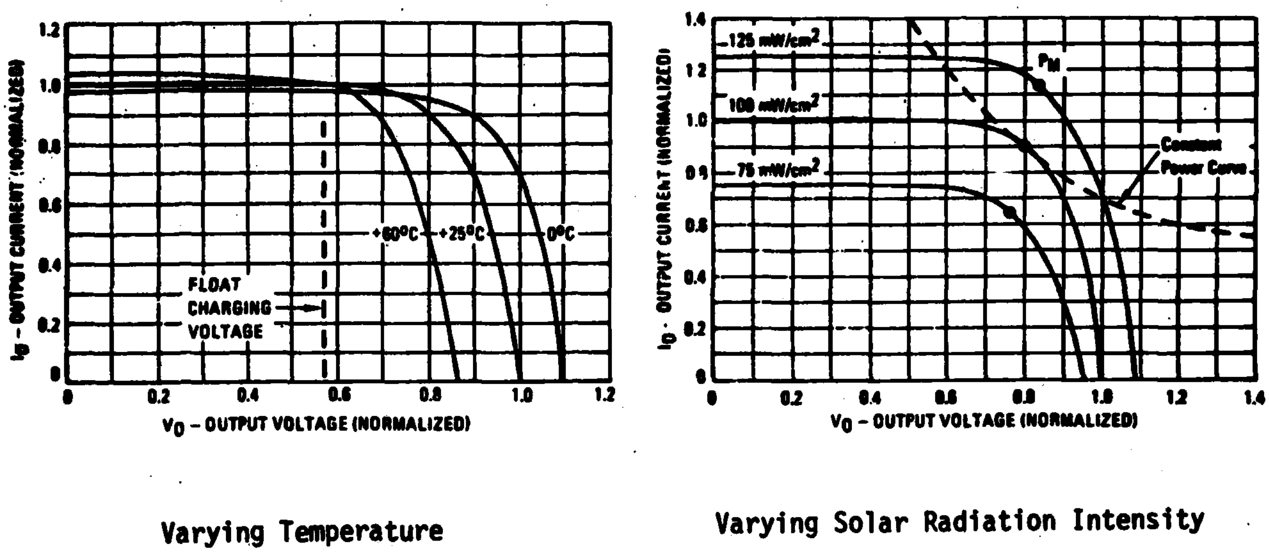

FIGURE 4. Effects of Varying Temperature and Solar Radiation Intensity on a Typical Photovoltaic Cell Characteristic Curve.

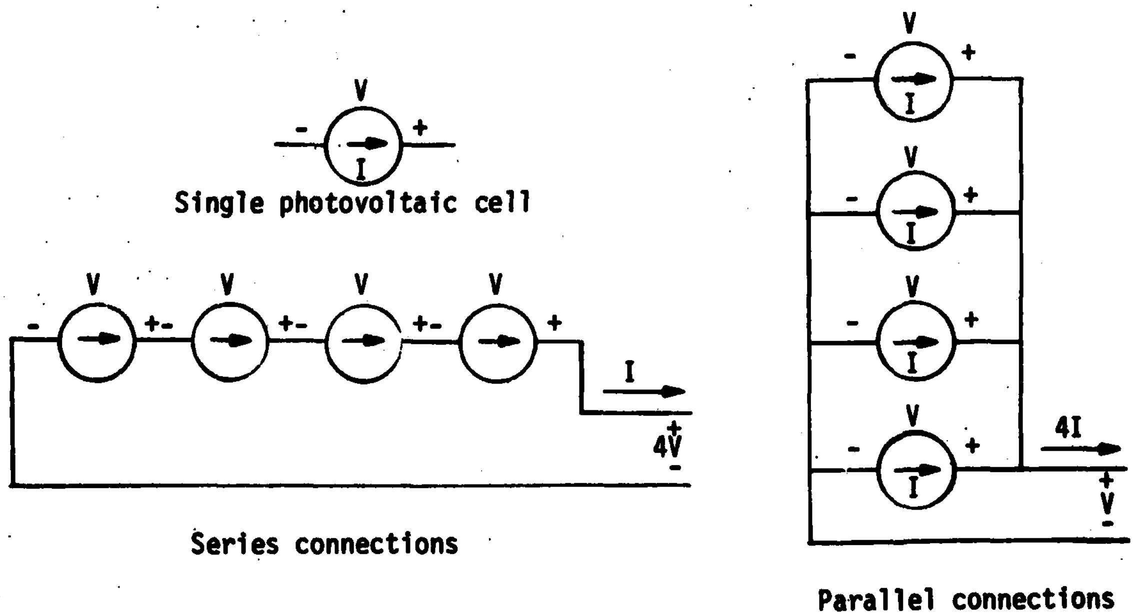

FIGURE 5. Photovoltaic Cell Series and Parallel Connections.

Photovoltaic Module

Virtually all photovoltaic power systems require power at a higher output than a single photovoltaic cell. Individual cells are assembled into photovoltaic modules because mounting single cells would be time-consuming and tedious. The modules usually contain 36 to 40 cells

connected in series. Modules are easier to handle and quicker to install than single cells. Like photovoltaic cells, modules can be connected in series for a higher system output voltage or in parallel for a higher system output current. A module is electrically no more than a preassembled block of cells and functions to protect the cells from the environment. The module is a sandwich of a superstrate (usually tempered glass), an encapsulant, photovoltaic cells, and a substrate laminated together under pressure and temperature. The lamination protects the cells from damage due to hail, wind, moisture, dirt, and handling.

Photovoltaic Array

The photovoltaic array is the entire field of modules connected in series and in parallel and mounted on a support structure.

Voltage Regulator

The voltage regulator adjusts the output voltage from the array to protect the battery storage. The regulator sets the charging voltage to maximize battery charging and at the same time acts to limit battery water loss from gassing due to battery overcharging.

Blocking Diode

The blocking diode prevents the battery storage from discharging through the voltage regulator or the photovoltaic array at night or on cloudy days.

Battery Storage

The battery storage is used to store energy produced by the array and not used by the load, and also to supply power to the load at night and on cloudy days. The ideal storage battery for a photovoltaic power system must hold a charge (have a low self-discharge) for an extended period of time. The battery must be able to survive a number of cycles of deep discharge and subsequent recharge, and must also have a long life with very little maintenance. The most commonly used storage battery is the lead-acid battery. In Table 1, the different types of available lead-acid batteries are compared; float service, pure lead, or lead-calcium batteries best meet all of the requirements for a photovoltaic power system battery storage.

Storage batteries are connected in series to increase the battery storage voltage and in parallel to increase the battery storage current. The current supplied by a series string of batteries will be the same as the current supplied by a single battery. The voltage supplied by parallel-connected batteries will be the same as the voltage supplied by a single battery. Figure 6 shows series and parallel battery connections.

Low-Voltage Cutoff

A low-voltage cutoff is used to disconnect the battery storage from the load to prevent damage to the batteries when being discharged too deeply.

TABLE 1. Types of Lead-A id Batteries.

BATTERY TYPE		ENERGY COST	ENERGY DENSITY	CHARACTERISTICS
		rated $/kWh	rated Wh/lb	
SLI	AUTO	$35-54	15-21	High self-discharge shallow discharge cycle short life under deep discharge conditions
	DIESEL	$60	16-18	
MOTIVE POWER	GOLF CART TYPE	$45-60	30-35	250 cycle life, high self-discharge, deep cycle
	LONG LIFE	$160-220	7-11	1,000-2,000 cycle life, high self-discharge deep cycle
FLOAT SERVICE	PURE LEAD GRID	$80-130	14-18	Low self-discharge, low maintenance
	LEAD-CALCIUM	$180-240	7-10	1,500 cycle life low self-discharge deep cycle capabilities
SEALED	FLOAT SERVICE	$140	14-18	Low maintenance, low self-discharge

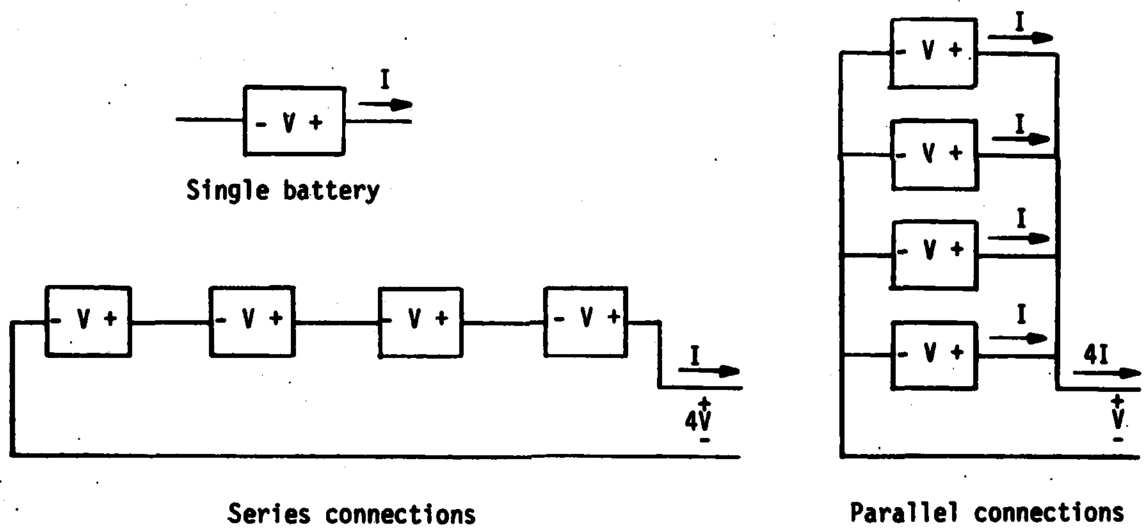

FIGURE 6. Series and Parallel Battery Connections.

Power Conditioning

The power-conditioning unit converts the power from the photovoltaic array or the battery storage to the type and quality of power required by the load. The power conditioning unit can be as simple as a voltage regulator or DC-to-DC converter, or as complex as a three-phase sine-wave inverter.

Application Load

The application load is the equipment that receives its power from the photovoltaic power system.

All photovoltaic power systems contain a photovoltaic array and an application load, but not necessarily a voltage regulator, blocking diode, battery storage, or a power conditioning unit. A properly designed photovoltaic power system for water pumping requires only the photovoltaic array and the application load. A voltage regulator is not needed if the pump motor can handle the photovoltaic array's voltage swing, and a water storage tank eliminates the need for battery storage. The components needed for a given application are determined by the requirements of the application load.

PHOTOVOLTAIC ARRAY SIZING

The photovoltaic power system functions as follows: The application load operates from the battery storage, and the photovoltaic array keeps the battery storage charged. In sizing the photovoltaic power system, the battery storage is sized to meet the load power requirements, and the photovoltaic array is sized to keep the battery storage charged. Appendix A contains all equations necessary to size photovoltaic power systems and includes a sizing worksheet to make system sizing easier.

The primary parameter in system sizing is the load power requirements, which must be accurately known. A useful photovoltaic power system cannot be properly sized without accurate load power requirements. Appendix B thoroughly covers the determination of load power requirements. Once these requirements are identified, the load (for sizing purposes) can be calculated using Equation 1.

$$\text{load (Wh/day)} = \frac{\text{duty cycle (Wh/day)}}{\text{power conditioning efficiency (decimal)}} \tag{1}$$

where

load (Wh/day) = the amount of power the photovoltaic power system must supply in watthours per day.

duty cycle (Wh/day) = the application instantaneous power draw times the number of hours per day the power is being drawn. If the power is used only part of the week, average it out over the entire week. If an application has more than one duty cycle, sum all of the duty cycles and enter the total in Equation 1. Duty cycle is in units of watthours per day.

power conditioning efficiency (decimal) = the efficiency in decimal form of the inverter or DC-to-DC converter. If there is no inverter or DC-to-DC converter, enter 1.0.

A complete example of the use of this sizing technique is included in Appendix B.

Photovoltaic modules used in stand-alone photovoltaic systems are designed to work well with battery storages. Batteries require a higher voltage during charging than they exhibit when they are providing power. For instance, a 12-volt battery needs a little more than 14 volts to be charged properly while it supplies power at 12 volts. Photovoltaic modules come in

fairly standard voltages to supply the required higher charging voltage. A 16-volt module is designed to provide the proper charging voltage for a 12-volt battery. The 16-volt module output is necessary to provide the higher charging voltage the battery requires and to provide for voltage losses in the photovoltaic power system. Photovoltaic modules are connected in series to increase the photovoltaic system voltage. Equation 2 is used to determine the number of photovoltaic modules required to charge a given battery storage (see example in Appendix B).

$$\begin{array}{c}\text{number of series}\\ \text{photovoltaic modules}\end{array} = \frac{\text{nominal battery storage voltage (VDC)}}{\text{nominal photovoltaic module voltage (VDC/module)}} \qquad (2)$$

where

nominal battery storage voltage (VDC) = the DC operating voltage level of the battery storage.

nominal photovoltaic module voltage (VDC/module) = the operating voltage of the battery that the photovoltaic module is designed to charge (e.g., a 16-volt photovoltaic module is designed to charge a 12-volt battery; the nominal voltage of the 16-volt module is 12 volts). The nominal photovoltaic module voltage is usually supplied on the module specification sheet (Appendix C).

If the results of Equation 2 contain a fraction of a module, round the number of series photovoltaic modules up to the next whole number (e.g., 8.4 photovoltaic modules is rounded up to 9).

Photovoltaic modules are connected in parallel to supply the current requirements of the application load. Equation 3 is used to determine the number of parallel modules necessary to supply the current requirements of a specified application load. Equation 3 must be solved for each month, and the largest answer must be used in the balance of the photovoltaic array sizing. Using the largest answer from Equation 3 ensures that the application load will be met by the photovoltaic system throughout the year (see example in Appendix B).

$$\begin{array}{c}\text{number of}\\ \text{parallel}\\ \text{photovoltaic}\\ \text{modules}\end{array} = \frac{\text{load (Wh/day)} \times 1.20}{\begin{array}{c}\text{nominal battery}\\ \text{storage voltage}\\ \text{(VDC)}\end{array} \times \begin{array}{c}\text{equivalent peak}\\ \text{hours per day}\\ \text{(h/day)}\end{array} \times \begin{array}{c}\text{nominal photovoltaic}\\ \text{module current}\\ \text{(A/module)}\end{array}} \qquad (3)$$

where

load (Wh/day) = result of Equation 1.

1.20 = a 20% safety factor to account for photovoltaic-array output degradation due to age and dirt.

nominal battery storage voltage (VDC) = the DC operating voltage level of the battery storage.

equivalent peak hours per day (h/day) = the equivalent hours per day that the photovoltaic array receives solar radiation at a level of 100 mW/cm^2 as specified in the Standard Test Conditions (discussed earlier under the heading, "Photovoltaic Cell"). The equivalent peak hours per day is computed by taking the total amount of solar radiation received by the surface of the array in a day and dividing it by the solar radiation level of 100 mW/cm^2 as specified in the Standard Test Conditions. This calculation provides the number of hours that the array would have to be exposed to the Standard Test Condition of 100 mW/cm^2 to receive the same amount of energy that the array received during the day.

The amount of solar radiation received by the surface of the array depends on the tilt angle of the array and the amount of solar radiation received by a horizontal surface at the array location. The horizontal solar radiation at a specific location (which includes weather effects), is usually found in all solar energy source books. The tilt angle of the photovoltaic array determines what amount of the horizontal solar radiation will be received by the tilted array surface. As a surface is tilted to the south, it receives more energy in the winter and less energy in the summer. Figure 7 shows the solar radiation received by a surface that is tilted 20, 35, and 50 degrees

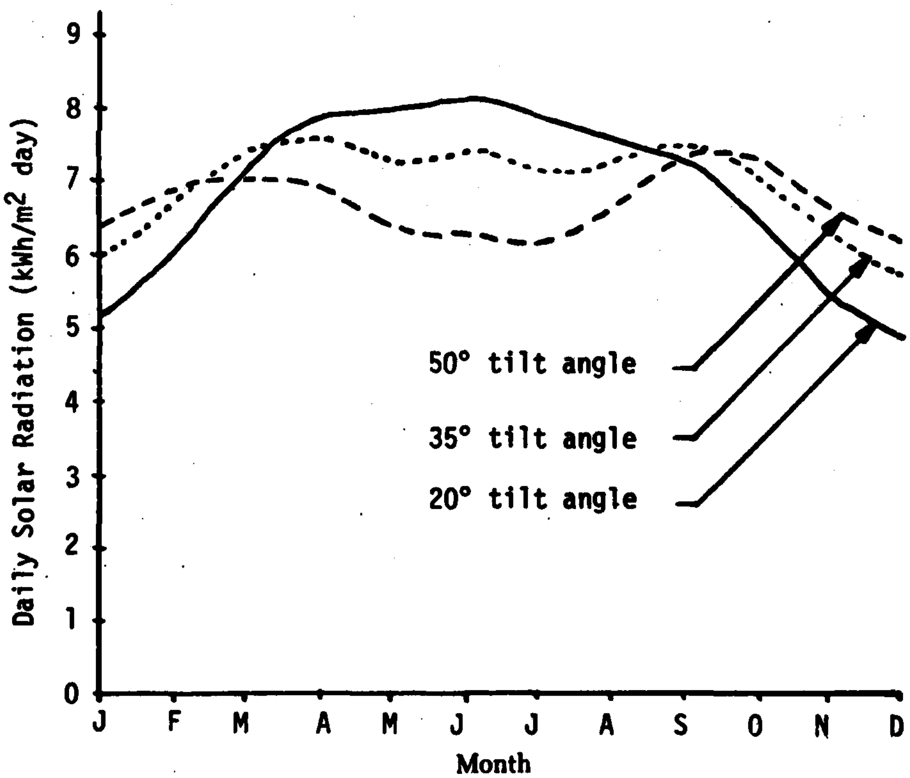

FIGURE 7. Solar Radiation Received by a Surface That Is Tilted at 20, at 35, and at 50 Degrees From the Horizontal at Albuquerque, N. Mex.

from the horizontal for Albuquerque, N. Mex. Figure 7 also shows that the amount of available solar radiation received by the photovoltaic array can be varied by adjusting the tilt angle.

The determination of the proper tilt angle for a photovoltaic power system depends on how the load power requirements compare to the solar radiation received by the tilted array surface. For constant year-round load requirements, the tilt angle should be adjusted so that the amount of energy received in the winter is as close as possible to the amount of energy received in the summer. For load requirements that vary from month to month, the tilt angle should be selected that best matches the yearly load profile to the profile of the yearly solar energy received. Once the tilt angle is selected, the equivalent peak hours per day can be determined.

The amount of solar radiation received by a tilted surface is very complicated to calculate. Appendix D contains tables of solar radiation received on a tilted surface for three common tilt angles for a number of cities. Equivalent peak hours per day can easily be determined by locating the table of solar radiation on a tilted surface for a city nearest the photovoltaic array location and dividing by 100 mW/cm^2 (1 kW/m^2). Values of equivalent peak hours per day are the same as the values of daily solar radiation given in units of kWh/m^2.

nominal photovoltaic module current (A/module) = the nominal module current output that is usually supplied on the module specification sheet (Appendix C). The nominal module current output is also designated as module test current, module current at peak power point, and module current.

The number of parallel photovoltaic modules should be rounded up to the next higher whole number if a fraction of a module results from Equation 3.

The total number of modules needed for the power system is equal to the number of series photovoltaic modules times the number of parallel photovoltaic modules. A photovoltaic array is most often defined and purchased in terms of peak watts. Peak watts is the power the array would supply when exposed to Standard Test Conditions. The total peak watts of an array are defined in Equation 4 (see example in Appendix B).

$$\begin{matrix}\text{total peak} \\ \text{watts (W)}\end{matrix} = \begin{matrix}\text{number of series} \\ \text{photovoltaic} \\ \text{modules}\end{matrix} \times \begin{matrix}\text{number of parallel} \\ \text{photovoltaic} \\ \text{modules}\end{matrix} \times \begin{matrix}\text{peak watts per} \\ \text{photovoltaic} \\ \text{module (W)}\end{matrix} \qquad (4)$$

where

number of series photovoltaic modules = the results of Equation 2.

number of parallel photovoltaic modules = the results of Equation 3.

peak watts per photovoltaic module (W) = peak watts supplied on the module specification sheet (Appendix C). Peak watts is also known as peak power.

BATTERY STORAGE SIZING

The battery storage is designed to provide the load with a continuous supply of power (1) for nights, (2) for a specified number of sunless days, and (3) to increase system reliability. The designed battery storage size is found by solving Equation 5 for each month to determine the largest required storage size. The largest answer from Equation 5 must be used in the balance of the battery storage sizing (see example in Appendix B).

$$\text{designed battery storage size (Wh)} = \frac{\text{load (Wh/day)} \times 1.20 \times \text{required days of storage (day)}}{\text{depth of discharge (decimal)}} \tag{5}$$

where

load (Wh/day) = load calculated in Equation 1.

1.20 = a 20% safety factor that compensates for storage degradation due to age.

required days of storage (day) = the number of consecutive sunless days the photovoltaic power system must operate. This number will be at least 1 and should be determined from weather information for the photovoltaic power system location.

depth of discharge (decimal) = the allowable depth of discharge that prolongs battery storage life and prevents the battery storage from freezing. Discharging a battery 100% will greatly shorten the storage battery life. In applications that are subject to freezing, sufficient battery storage capacity must remain to prevent the battery storage from freezing. Figure 8 shows a typical battery design curve and provides the information necessary to determine the allowable battery storage depth of discharge. Determine the minimum temperature the battery storage would be likely to experience and, from Figure 8, find the allowable depth of discharge that corresponds to this temperature. The depth of discharge must be in decimal form (80% = 0.80) and should be no greater than 0.80.

The number of series-connected batteries is calculated by Equation 6 (see example in Appendix B).

$$\text{number of series batteries} = \frac{\text{nominal battery storage voltage (VDC)}}{\text{nominal single battery voltage (VDC/battery)}} \tag{6}$$

where

nominal battery storage voltage (VDC) = the DC operating voltage level of the battery storage.

nominal single battery voltage (VDC/battery) = nominal single battery voltage supplied on the product specification sheet. See Appendix E for a sample specification sheet.

The number of series batteries should be rounded up to the next higher whole number if a fraction results from Equation 6.

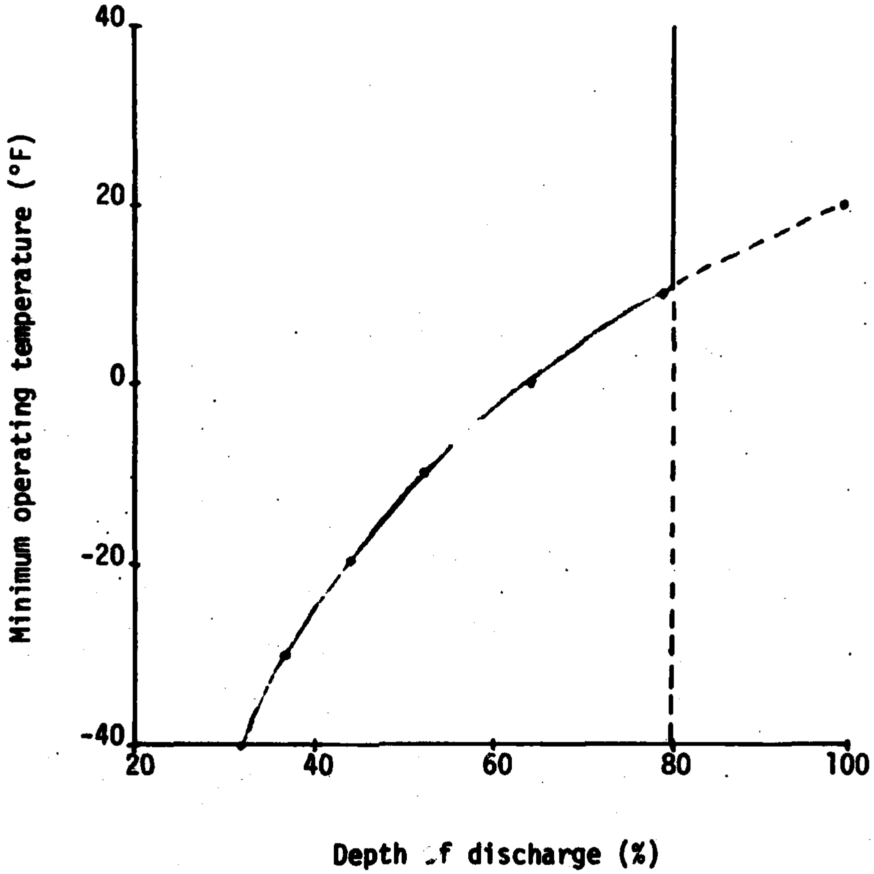

FIGURE 8. Battery Storage Depth of Discharge as a Function of Battery Storage Minimum Operating Temperature.

The number of batteries required to be connected in parallel is calculated by Equation 7 (see example in Appendix B).

$$\text{number of parallel batteries} = \frac{\text{designed battery storage size (Wh)}}{\text{nominal battery storage voltage (VDC)} \times \text{nominal ampere hours per battery (Ah/battery)}} \quad (7)$$

where

designed battery storage size (Wh) = result of Equation 5.

nominal battery storage voltage (VDC) = the DC operating voltage level of the battery storage.

nominal ampere hours per battery (Ah/battery) = the ampere hour capacity of the selected storage battery. The ampere hour capacity depends on the discharge current.

Higher discharge currents provide for lower ampere hour capacities for the same battery. The ampere hour capacity should be selected for the average battery discharge current. If this value cannot be determined, use the design ampere hour capacity supplied on the battery specification sheet (Appendix E).

The number of parallel batteries should be rounded up to the next higher whole number if a fraction results from Equation 7.

The actual battery storage size is calculated from Equation 8 (see example in Appendix B).

$$\begin{array}{c}\text{actual battery}\\ \text{storage size (Wh)}\end{array} = \begin{array}{c}\text{number of}\\ \text{series}\\ \text{batteries}\end{array} \times \begin{array}{c}\text{number of}\\ \text{parallel}\\ \text{batteries}\end{array} \times \begin{array}{c}\text{nominal}\\ \text{ampere hours per}\\ \text{battery (Ah)}\end{array} \times \begin{array}{c}\text{nominal}\\ \text{single battery}\\ \text{voltage (VDC)}\end{array} \qquad (8)$$

where

number of series batteries = result of Equation 6.

number of parallel batteries = result of Equation 7.

nominal ampere hours per battery (Ah) = the design ampere hour capacity of the battery. The design ampere hour capacity is supplied on the battery specification sheet (Appendix E).

nominal single battery voltage (VDC) = nominal single battery voltage supplied on the battery specification sheet (Appendix E).

Actual battery storage size is often discussed in terms of kilowatthours of storage capacity. Divide watthours by 1000 to convert to kilowatthours.

The battery storage must be able to supply the peak battery current requirement of the load. The ability of the battery storage to meet the peak battery current requirement can be determined by the following steps.

Step 1. Calculate the peak battery current requirement in amperes by using Equation 9 (see example in Appendix B).

$$\begin{array}{c}\text{peak battery current}\\ \text{requirement (A)}\end{array} = \frac{\text{peak load power requirement (W)}}{\begin{array}{c}\text{nominal battery}\\ \text{storage voltage (VDC)}\end{array} \times \begin{array}{c}\text{number of parallel}\\ \text{batteries}\end{array}} \qquad (9)$$

where

peak load power requirement (W) = the largest load power requirement in watts divided by the inverter efficiency, if any (in decimal form).

nominal battery storage voltage (VDC) = the DC operating voltage level of the battery storage.

number of parallel batteries = result of Equation 7.

Step 2. Use the peak battery current requirement from Equation 9 and the battery design curve (Appendix E) to determine the number of hours the peak battery current can be supplied by the battery. Be sure to adjust the design curve to the minimum operating temperature of the battery storage.

Step 3. Check to be sure that the number of hours the peak battery current can be supplied is sufficient to meet the load duty cycle for the peak load power requirement of Equation 9 times the required days of storage.

Step 4. If the battery cannot supply the peak battery current requirement for the load duty cycle in step 3, add additional parallel strings of batteries to the battery storage and go back to step 1. When sufficient parallel battery strings have been added to meet the peak battery current requirement, recalculate Equation 8 using the new number of parallel battery strings.

PHOTOVOLTAIC POWER SYSTEM COST ANALYSIS

Photovoltaic power systems are cost-effective and should be purchased when the life-cycle cost of the photovoltaic power system is less than the life-cycle cost of the competing conventional power source. The competing power source may be diesel generators, batteries, or the extension of a distant utility grid. Life-cycle costs indicate the amount of money needed today to cover the cost of the system throughout its economic life. These costs include one-time capital, operating, and maintenance costs that are adjusted for the effects of inflation and interest rates. Cost work sheets in Appendix A are used to help in making the cost analysis.

The one-time capital costs for a photovoltaic power system include costs for initial purchase, installation, and future battery replacement. The yearly operating and maintenance costs include checking battery and photovoltaic array conditions. The estimated life of a photovoltaic power system is 25 years with the batteries being replaced every 10 years.

The one-time capital costs for a diesel generating power system include the cost of the diesel generators and the fuel storage system. The yearly operating and maintenance costs include diesel maintenance and fuel costs. The estimated life of a diesel generator is 25 years.

The one-time cost for a battery power source is the initial and future replacement costs of the battery. The operating and maintenance costs include checking and recharging the battery. The estimated life of a battery energy source is 10 years.

The one-time cost for an extended utility grid power source is the cost of extension. The operating and maintenance costs include energy costs and line- and transformer-inspection costs. The estimated life of a utility grid is 25 years.

Figure 9 shows the relative cash flows for the photovoltaic power system and the three alternate power sources. The cash flows show how money will be spent on the power source throughout its economic life. The displayed values are taken from the example in Appendix B.

Calculating life-cycle costs involves more than simply adding up the cash flows in Figure 9. Because of inflation and interest rates, $1 in the future will not be equal to $1 today.

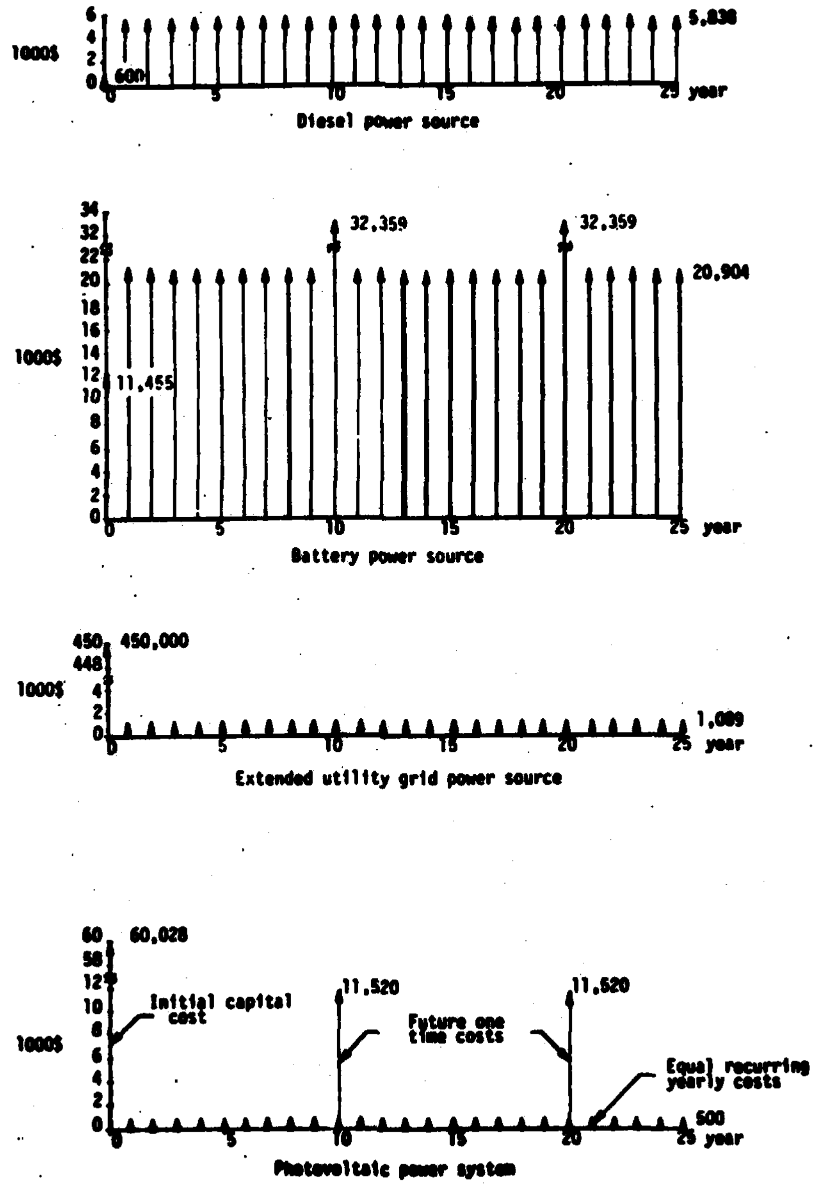

FIGURE 9. Relative Cash Flow Diagrams for Four Power Sources.

This changing value of future money is known as the time value of money. One dollar invested at 7% interest will be worth $1.07 in 1 year and $1.145 in 2 years. One dollar today will be worth more in the future, and likewise, if $1 will be needed in the future, less than $1 is needed to be invested today. Inflation works the same way except that money shrinks in value instead of growing.

The combined effects of interest and inflation on the time value of money have been conveniently computed in the tables in Appendix F. These tables show inflation-discount factors and will give the present (today's) value of future costs. The Differential Inflation Rate

is used when the price of the energy source being evaluated (for example, gasoline) has a higher inflation rate than the general economy. The discount rate is the interest rate the Navy assumes for economic analysis. The single-amount discount factor is used to determine the present value of a one-time future cost that is calculated by multiplying the future cost by the single-amount factor for the project year in which the cost occurs. The proper table to use is determined by the Differential Inflation Rate. The cumulative-uniform-series discount factor is used to determine the present value of an equal recurring yearly cost. For applications that use the same amount of energy each year, the annual fuel cost would be an equal recurring yearly cost. The present value of an equal recurring yearly cost is calculated by multiplying the equal recurring yearly cost by the cumulative-uniform-series discount factor corresponding to the number of years the equal recurring yearly cost will occur (usually the economic life of the system).

Equation 10 is used to determine the life-cycle cost, or present value, of any of the four energy sources (see example in Appendix B).

$$\begin{array}{c}\text{life-cycle cost}\\ \text{(present value) (\$)}\end{array} = \begin{array}{c}\text{initial one-}\\ \text{time cost (\$)}\end{array} + \begin{array}{c}\text{future one-}\\ \text{time cost (\$)}\end{array} \times \begin{array}{c}\text{single-amount}\\ \text{discount factor}\end{array}$$

$$+ \begin{array}{c}\text{equal recurring}\\ \text{yearly costs (\$)}\end{array} \times \begin{array}{c}\text{cumulative-uniform-}\\ \text{series discount factor}\end{array} \qquad (10)$$

where

initial one-time cost ($) = initial cost of the power source.

future one-time cost ($) = cost of one-time future expenses. Battery replacement would be a future one-time cost at years 10 and 20. If more than one future one-time cost occurs, multiply it by the appropriate single-amount discount factor and add the result to Equation 10.

single-amount discount factor = that obtained from the appropriate Differential Inflation Rate table in Appendix F. Select the single-amount discount factor corresponding to the year of the future one-time cost.

equal recurring yearly costs ($) = costs that are the same and occur from year to year. Fuel costs and operating and maintenance costs are usually equal recurring yearly costs.

cumulative-uniform-series discount factor = that obtained from the appropriate Differential Inflation Rate table in Appendix F. Select the cumulative-uniform-series discount factor corresponding to the number of years the equal recurring yearly costs occur.

The following Differential Inflation Rates can be assumed if more accurate information is unavailable.

Differential Inflation Rate of oil or gas is 8%.
Differential Inflation Rate of electricity is 7%.
Differential Inflation Rate of other items discussed is 0%.

Photovoltaic power systems are cost-effective and should be purchased when their life-cycle costs are less than the life-cycle costs of the conventional power sources. The life-cycle cost considerations of the conventional sources are fairly straightforward and easy to compute.

The one-time capital cost of a diesel power source includes diesel generator and fuel storage costs. These costs can be determined from actual acquisition costs of similar systems. The operating and maintenance costs are also determined from actual costs. In many remote applications, the cost of fuel and fuel delivery plus the maintenance costs, which include parts and labor and transportation costs of the maintenance crew, can result in a very high recurring yearly cost. The recurring yearly cost can very easily be higher than the one-time capital cost.

The one-time capital cost of a battery power system can easily be determined from actual battery costs. Replacement battery costs can be assumed to be the same as the initial battery capital cost, and they will occur at the end of the battery power system's useful life. The operating and maintenance costs of a remote battery power system are very high. Personnel must regularly take the batteries to the charging station and return them to the application site, or a second bank of batteries must be purchased so that one bank will always be charged to replace the other bank at the application site. The cost of the electricity in recharging the batteries must be included in the operating cost of the system.

The one-time capital cost of extending an existing utility grid to a remote location can be obtained from the local utility company. The operating and maintenance costs are for occasional inspection of the utility distribution line and the cost of the electricity supplied to the application.

The one-time cost of a photovoltaic power system includes the initial procurement and installation costs. The one-time future cost is the battery replacement cost. The operating and maintenance costs, which are for visual inspection of the photovoltaic array and maintenance of the battery storage, are low and can be determined with reasonable accuracy. The big unknown is the initial procurement and installation costs of a photovoltaic power system.

Whereas the costs of the conventional power systems can be easily determined by the using activity, the costs of a photovoltaic power system are supplied by this report, using Equations 11 and 12 (see examples in Appendix B). Equation 11 is used to calculate the one-time procurement cost.

$$\begin{array}{c}\text{initial one-time}\\\text{procurement cost}\\\text{of a photovoltaic}\\\text{power system (\$)}\end{array} = \begin{array}{c}\text{total peak}\\\text{watts (W)}\end{array} \times \begin{array}{c}\text{photovoltaic module}\\\text{cost per watt (\$/W)}\end{array} + \begin{array}{c}\text{total peak}\\\text{watts (W)}\end{array} \times \begin{array}{c}\text{voltage regulator}\\\text{cost per watt (\$/W)}\end{array}$$

$$+ 60\ (\$) + \begin{array}{c}\text{total peak}\\\text{watts (W)}\end{array} \times \begin{array}{c}\text{arraying}\\\text{cost per watt (\$/W)}\end{array} + \begin{array}{c}\text{actual battery}\\\text{storage size (Wh)}\end{array}$$

$$\times \begin{array}{c}\text{battery cost}\\\text{per watthour (\$/Wh)}\end{array} + \begin{array}{c}\text{total peak}\\\text{inverter watts (W)}\end{array} \times \begin{array}{c}\text{inverter}\\\text{cost per watt (\$/W)}\end{array} + 690\ (\$) \qquad (11)$$

where

total peak watts (W) = result of Equation 4.

photovoltaic module cost per watt (\$/W) = cost information obtained from the photovoltaic module specification sheet (Appendix C). The cost must be in \$/W, so it may be necessary to divide the module cost by the module peak watts to obtain the \$/W. If no actual cost information is available, use the curve in Figure 10, which shows the expected cost of photovoltaic modules in \$/W for the next several years.

voltage regulator cost per watt (\$/W) = 0.20 \$/W.

60 (\$) = the minimum amount that a voltage regulator would cost. Do not include the 60 \$ if no voltage regulators are used.

arraying cost per watt (\$/W) = arraying includes photovoltaic support structure, wiring harnesses, and connectors. Arraying cost is estimated at 1.25 \$/W.

actual battery storage size (Wh) = result of Equation 8.

battery cost per watthour (\$/Wh) = 0.16 \$/Wh.

total peak inverter watts (W) = the largest power requirement the inverter must supply in watts. If the photovoltaic power system has more than one inverter, add the peak inverter watts of each together.

inverter cost per watt (\$/W) = 1.16 \$/W.

690 (\$) = the minimum amount that an inverter would cost. Do not include the 690 \$ if no inverter is used.

When these assumptions are used, Equation 11 reads as follows:

$$\begin{aligned}\begin{matrix}\text{initial one-time}\\\text{procurement cost}\\\text{of a photovoltaic}\\\text{power system (\$)}\end{matrix} &= \begin{matrix}\text{total peak}\\\text{watts (W)}\end{matrix} \times \begin{matrix}\text{photovoltaic module}\\\text{cost per watt (\$/W)}\end{matrix} + \begin{matrix}\text{total peak}\\\text{watts (W)}\end{matrix} \times 0.20\ (\$/\text{W})\\ &+ 60\ (\$) + \begin{matrix}\text{total peak}\\\text{watts (W)}\end{matrix} \times 1.25\ (\$/\text{W}) + \begin{matrix}\text{actual battery}\\\text{storage size (Wh)}\end{matrix}\\ &\times 0.16\ (\$/\text{Wh}) + \begin{matrix}\text{total peak}\\\text{inverter watts (W)}\end{matrix} \times 1.16\ (\$/\text{W}) + 690\ (\$)\end{aligned} \tag{11}$$

Equation 12 is used to calculate the installation cost of a photovoltaic power system.

$$\begin{matrix}\text{installation cost of a}\\\text{photovoltaic power system (\$)}\end{matrix} = \begin{matrix}\text{total peak}\\\text{watts (W)}\end{matrix} \times \begin{matrix}\text{installation}\\\text{cost per watt (\$/W)}\end{matrix} \tag{12}$$

where

total peak watts (W) = result of Equation 4.

installation cost per watt (\$/W) = 17.0 \$/W.

The total one-time capital cost of a photovoltaic power system is the sum of the results of Equations 11 and 12.

The future battery replacement cost is computed from Equation 13 (see example in Appendix B).

$$\text{future battery replacement cost (\$)} = \text{actual battery storage size (Wh)} \times 0.16\ (\$/\text{Wh}) \tag{13}$$

where

actual battery storage size (Wh) = result of Equation 8.

0.16 ($/Wh) = battery cost per watthour.

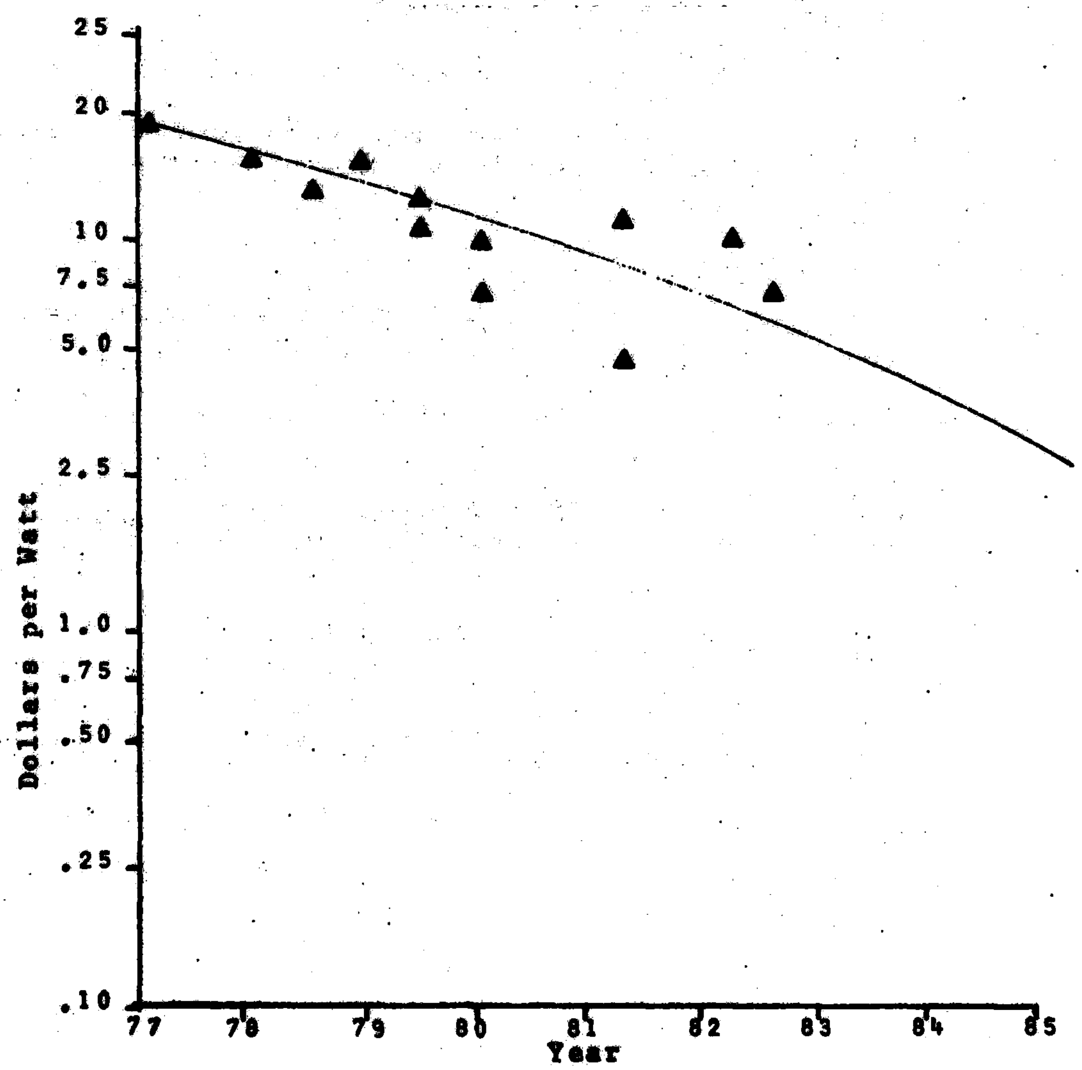

FIGURE 10. Projected Photovoltaic Module Cost.

Equation 14 provides the operating and maintenance costs of a photovoltaic power system (see example in Appendix B).

$$\begin{array}{c}\text{operating and maintenance}\\ \text{costs of a photovoltaic}\\ \text{power system (\$/yr)}\end{array} = \begin{array}{c}\text{actual battery}\\ \text{storage size (Wh)}\end{array} \times 0.001\ (\$/\text{Wh})$$

$$+ \begin{array}{c}\text{personnel}\\ \text{transportation}\\ \text{costs per trip (\$/trip)}\end{array} \times 2\ (\text{trips/yr}) \qquad (14)$$

where

actual battery storage size (Wh) = result of Equation 8.

0.001 ($/Wh) = cost of performing battery maintenance per watthour of battery capacity. (Photovoltaic array requires no maintenance.)

personnel transportation costs per trip ($/trip) = hourly cost of personnel times the number of personnel times round-trip travel time plus vehicle cost, if any.

2 (trips/yr) = two battery maintenance trips each year.

Some Navy funding procedures may require that a photovoltaic power system be cost-effective in fewer years than its economic life. For these systems, perform the life-cycle cost comparisons only for the portions of the cash flow diagrams in Figure 9 that fall within the specified number of years.

In any life-cycle cost analysis that shows the photovoltaic power system as not cost-effective, it is useful to determine when, if ever, the system would become cost-effective. The photovoltaic module cost has the greatest impact on the cost of the photovoltaic power system and is most likely to change with time (Figure 10). The other items are not very time dependent. The photovoltaic module cost that makes the power system cost-effective is known as the economic module cost, which can be determined by the following steps.

Step 1. Calculate the lowest life-cycle cost of the three competing conventional power sources by using Equation 10.

Step 2. Use the lowest life-cycle cost from step 1 and use Equation 10 to calculate the cost-effective initial one-time cost for the photovoltaic power system.

Step 3. Use the answer in step 2 and Equations 11 and 12 to calculate the economic module cost by solving for the photovoltaic module cost per watt in Equation 11 (only unknown term).

If the economic module cost is negative, the photovoltaic power system will never be cost-effective. If the cost is positive, Figure 10 will indicate in what year the photovoltaic power system will be cost-effective.

CONCLUSIONS

Photovoltaic power systems are viable alternatives to conventional power sources for remote applications. These systems are life-cycle cost-effective when the remote-application costs are high for operating and maintaining diesel generators and battery power sources and initially extending an existing utility grid.

Photovoltaic systems will supply reliable, quiet, pollution-free power. They use a renewable natural resource and therefore require no refueling. A radio-controlled switch can be used to turn the system on and off, when desired, making it unnecessary for personnel to man the site. The ability to operate satisfactorily for long unattended periods of time in very remote locations makes photovoltaic systems ideal for remote mountain-top applications such as communication equipment.

Due to the high initial costs of photovoltaic power systems, they are currently cost-effective primarily for small, remote applications. As the photovoltaic module costs decrease, the systems will become cost-effective for larger, remote applications and finally for grid-connected applications. Photovoltaic systems receive their power from solar radiation and are therefore primarily limited for use in sunny locations.

Following is a list of remotely located applications that are representative of the types of loads most likely to be cost-effective for photovoltaic power use. These and similar applications should be investigated for possible conversion to photovoltaic power.

1. Monitoring and sensing devices:
   - remote weather stations/transmitters
   - remote air- and water-pollution monitoring
   - sunrise and sunset indicators
   - seismic detectors/transmitters
   - snow/rain gauges
   - flood monitors
   - oceanographic data platforms

2. Marking and warning devices:
   - obstruction/hazard lights
   - navigational aids/systems
   - VOR
   - VORTAC
   - TACAN
   - rotating beacons
   - sonar buoys and underwater channel markers
   - offshore-platform navigation aids
   - railroad-crossing signals
   - highway-sign defrosters
   - radar-boresight beacons

3. Communication equipment:
   - microwave repeaters
   - field-telephone system

telephone call box
low-frequency communication
radio telephones
pocket paging systems

4. Lighting:
   signs
   remote airfields
   remote sites

5. Remote instrumentation:
   data links
   telemetry
   remote instrumentation sites
   buildings
   camera stations
   radar
   beacons
   repeaters
   closed-circuit remote TV
   bomb-scoring devices

6. Comfort facilities

7. Security:
   remotely controlled and monitored gates
   IR, TV seismic-intrusion devices
   sentry sites
   electrified fences
   TV monitors

8. Battery charging

9. Boating applications

10. Radar for speed control

11. Field mess

12. Power for mini/microcomputers/calculators

13. Battery-charged tools

14. Space heating, cooling, ventilating at specific sites

15. Fire-alarm systems

16. Insect repellents

17. Power for intelligence units

18. Water pumping

19. Water purification/desalination

20. Power pumps to circulate solar hot water

21. Fuel pumping

22. Power source for life rafts (water purification, brewing coffee, sending distress signals, radio reception and transmission)

23. Power for automatic gates and doors

24. Distress/emergency beacons

25. Event recorder

26. Modular power for self-supportive stations (Seabees)

27. Low-energy lasers

28. Cathodic protection:
    pipelines
    wellheads and casings
    highway bridges
    underground storage

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Appendix A

EQUATIONS AND WORKSHEETS FOR PHOTOVOLTAIC POWER SYSTEM SIZING AND COST ANALYSIS

Equation 1

$$\text{load (Wh/day)} = \frac{\text{duty cycle (Wh/day)}}{\text{power conditioning efficiency (decimal)}}$$

Equation 2

$$\begin{array}{c}\text{number of series}\\ \text{photovoltaic modules}\end{array} = \frac{\text{nominal battery storage voltage (VDC)}}{\text{nominal photovoltaic module voltage (VDC/module)}}$$

Equation 3

$$\begin{array}{c}\text{number of}\\ \text{parallel}\\ \text{photovoltaic}\\ \text{modules}\end{array} = \frac{\text{load (Wh/day)} \times 1.20}{\begin{array}{c}\text{nominal battery}\\ \text{storage voltage}\\ \text{(VDC)}\end{array} \times \begin{array}{c}\text{equivalent peak}\\ \text{hours per day}\\ \text{(h/day)}\end{array} \times \begin{array}{c}\text{nominal photovoltaic}\\ \text{module current}\\ \text{(A/module)}\end{array}}$$

Equation 4

$$\begin{array}{c}\text{total peak}\\ \text{watts (W)}\end{array} = \begin{array}{c}\text{number of series}\\ \text{photovoltaic}\\ \text{modules}\end{array} \times \begin{array}{c}\text{number of parallel}\\ \text{photovoltaic}\\ \text{modules}\end{array} \times \begin{array}{c}\text{peak watts per}\\ \text{photovoltaic}\\ \text{module (W)}\end{array}$$

Equation 5

$$\begin{array}{c}\text{designed battery}\\ \text{storage size (Wh)}\end{array} = \frac{\text{load (Wh/day)} \times 1.20 \times \text{required days of storage (day)}}{\text{depth of discharge (decimal)}}$$

Equation 6

$$\begin{array}{c}\text{number of}\\ \text{series batteries}\end{array} = \frac{\text{nominal battery storage voltage (VDC)}}{\text{nominal single battery voltage (VDC/battery)}}$$

Equation 7

$$\begin{array}{c}\text{number of}\\ \text{parallel}\\ \text{batteries}\end{array} = \frac{\text{designed battery storage size (Wh)}}{\begin{array}{c}\text{nominal battery}\\ \text{storage voltage (VDC)}\end{array} \times \begin{array}{c}\text{nominal ampere hours}\\ \text{per battery (Ah/battery)}\end{array}}$$

Equation 8

$$\text{actual battery storage size (Wh)} = \text{number of series batteries} \times \text{number of parallel batteries} \times \text{nominal ampere hours per battery (Ah)} \times \text{nominal single battery voltage (VDC)}$$

Equation 9

$$\text{peak battery current requirement (A)} = \frac{\text{peak load power requirement (W)}}{\text{nominal battery storage voltage (VDC)} \times \text{number of parallel batteries}}$$

Equation 10

$$\text{life-cycle cost (present value) (\$)} = \text{initial one-time cost (\$)} + \text{future one-time cost (\$)} \times \text{single-amount discount factor}$$
$$+ \text{equal recurring yearly costs (\$)} \times \text{cumulative-uniform-series discount factor}$$

Equation 11

$$\text{initial one-time procurement cost of a photovoltaic power system (\$)} = \text{total peak watts (W)} \times \text{photovoltaic module cost per watt (\$/W)} + \text{total peak watts (W)} \times \text{voltage regulator cost per watt (\$/W)}$$
$$+ 60\ (\$) + \text{total peak watts (W)} \times \text{arraying cost per watt (\$/W)} + \text{actual battery storage size (Wh)}$$
$$\times \text{battery cost per watthour (\$/Wh)} + \text{total peak inverter watts (W)} \times \text{inverter cost per watt (\$/W)} + 690\ (\$)$$
$$= \text{total peak watts (W)} \times \text{photovoltaic module cost per watt (\$/W)} + \text{total peak watts (W)} \times 0.20\ (\$/W)$$
$$+ 60\ (\$) + \text{total peak watts (W)} \times 1.25\ (\$/W) + \text{actual battery storage size (Wh)}$$
$$\times 0.16\ (\$/Wh) + \text{total peak inverter watts (W)} \times 1.16\ (\$/W) + 690\ (\$)$$

Equation 12

$$\begin{matrix}\text{installation cost of a} \\ \text{photovoltaic power system (\$)}\end{matrix} = \begin{matrix}\text{total peak} \\ \text{watts (W)}\end{matrix} \times \begin{matrix}\text{installation} \\ \text{cost per watt (\$/W)}\end{matrix}$$

$$= \begin{matrix}\text{total peak} \\ \text{watts (W)}\end{matrix} \times 17.0 \text{ (\$/W)}$$

Equation 13

$$\begin{matrix}\text{future battery} \\ \text{replacement cost (\$)}\end{matrix} = \begin{matrix}\text{actual battery} \\ \text{storage size (Wh)}\end{matrix} \times 0.16 \text{ (\$/Wh)}$$

Equation 14

$$\begin{matrix}\text{operating and maintenance} \\ \text{costs of a photovoltaic} \\ \text{power system (\$/yr)}\end{matrix} = \begin{matrix}\text{actual battery} \\ \text{storage size (Wh)}\end{matrix} \times 0.001 \text{ (\$/Wh)}$$

$$+ \begin{matrix}\text{personnel} \\ \text{transportation} \\ \text{costs per trip (\$/trip)}\end{matrix} \times 2 \text{ (trips/yr)}$$

Photovoltaic Array Sizing Worksheet

Equation 1. Load (Wh/day) = $\dfrac{\text{\_\_\_\_ W X \_\_\_\_ h/day X \_\_\_\_ day/week}}{\text{7 day/week X \_\_\_\_ efficiency in decimal form}}$ = ____ Wh/day

Equation 2. Number of series photovoltaic modules = $\dfrac{\text{\_\_\_\_ VDC (nominal storage voltage)}}{\text{\_\_\_\_ VDC (nominal module voltage)}}$ = ____ modules

Equation 3. Number of parallel photovoltaic modules =

	Load (Wh/day)				Nominal battery storage voltage (VDC)		Equivalent peak hours per day (h/day)		Nominal photovoltaic module current (A/module)		Number of parallel photovoltaic modules: Calc.	Number of parallel photovoltaic modules: Next higher whole number
Jan		X	1.20	÷		÷		÷		=		
Feb		X	1.20	÷		÷		÷		=		
Mar		X	1.20	÷		÷		÷		=		
Apr		X	1.20	÷		÷		÷		=		
May		X	1.20	÷		÷		÷		=		
Jun		X	1.20	÷		÷		÷		=		
Jul		X	1.20	÷		÷		÷		=		
Aug		X	1.20	÷		÷		÷		=		
Sep		X	1.20	÷		÷		÷		=		
Oct		X	1.20	÷		÷		÷		=		
Nov		X	1.20	÷		÷		÷		=		
Dec		X	1.20	÷		÷		÷		=		largest answer ____

Equation 4. Total peak (W) watts = ____ (answer from Equation 2) X ____ (largest answer from Equation 3) X ____ W (peak watts per module) = ____ W

Battery Storage Sizing Worksheet

Equation 5. Designed battery storage size (Wh) =

	Load (Wh/day)				Required days of storage (day)		Depth of Discharge (decimal)		Designed battery storage size (Wh)
Jan		X	1.20	X		÷		=	
Feb		X	1.20	X		÷		=	
Mar		X	1.20	X		÷		=	
Apr		X	1.20	X		÷		=	
May		X	1.20	X		÷		=	
Jun		X	1.20	X		÷		=	
Jul		X	1.20	X		÷		=	
Aug		X	1.20	X		÷		=	
Sep		X	1.20	X		÷		=	
Oct		X	1.20	X		÷		=	
Nov		X	1.20	X		÷		=	
Dec		X	1.20	X		÷		=	
									largest answer ______

Equation 6. Number of series batteries = $\dfrac{\text{\_\_\_\_ VDC (nominal storage voltage)}}{\text{\_\_\_\_ VDC/battery (nominal battery voltage)}}$ = ______ batteries

Equation 7. Number of parallel batteries = $\dfrac{\text{\_\_\_\_ Wh (largest answer from Equation 5)}}{\text{\_\_\_\_ VDC} \begin{pmatrix}\text{nominal} \\ \text{storage voltage}\end{pmatrix} \times \text{\_\_\_\_ Ah/battery} \begin{pmatrix}\text{nominal amphours} \\ \text{per battery}\end{pmatrix}}$ = ______ batteries

Equation 8. Actual battery (Wh) storage size = ______ $\begin{pmatrix}\text{answer from} \\ \text{Equation 6}\end{pmatrix}$ X ______ $\begin{pmatrix}\text{answer from} \\ \text{Equation 7}\end{pmatrix}$ X ______ Ah/battery $\begin{pmatrix}\text{nominal amphours} \\ \text{per battery}\end{pmatrix}$

X ______ VDC $\begin{pmatrix}\text{nominal} \\ \text{battery voltage}\end{pmatrix}$ = ______ Wh

Battery storage ability to supply peak current requirement.

Step 1. Solve Equation 9.

Equation 9. Peak battery (A) current requirement = $\dfrac{\text{\_\_\_\_ W (peak load)}}{\text{\_\_\_\_ VDC} \begin{pmatrix}\text{nominal} \\ \text{storage voltage}\end{pmatrix} \times \text{\_\_\_\_} \begin{pmatrix}\text{answer from} \\ \text{Equation 7}\end{pmatrix}}$ = ______ A

Step 2. Number of hours battery storage can supply answer from Equation 9 = ______ hours

Step 3. Number of hours battery storage is required to supply answer from Equation 9 = ______ h/day $\begin{pmatrix}\text{duty cycle of} \\ \text{peak load}\end{pmatrix}$ X ______ day $\begin{pmatrix}\text{required days} \\ \text{of storage}\end{pmatrix}$

= ______ hours

Step 4. If answer in step 3 is less than answer in step 2, the battery storage design is satisfactory. If answer in step 3 is greater than the answer in step 2, add 1 parallel string of batteries and go back to step 1. When the answer in step 3 is finally less than the answer in step 2, use the new number of parallel strings of batteries and recalculate equation 8.

Cost Worksheet

Equation 10. Life cycle cost ($) for diesel power source = ______$ (diesel generator cost) + ______$ (fuel storage cost) + ______$ (yearly fuel cost)

X ______ (cumulative uniform series (CUS) discount factors for differential inflation rate (DIR) of 8%) + ______$ (yearly maintenance cost)

X ______ (CUS for DIR of 0%) = ______$

Equation 10. Life cycle cost ($) for battery power source = ______$ (battery cost) + ______$ (first battery replacement cost) X ______ (first single amount (SA) discount factor for DIR of 0%)

\+ ______$ (second battery replacement cost) X ______ (second SA for DIR of 0%) + ______$ (yearly cost of electricity)

X ______ (CUS for DIR of 7%) + ______$ (yearly maintenance cost) X ______ (CUS for DIR of 0%) = ______$

Equation 10. Life cycle cost ($) for extending utility grid = ______$ (extension cost) + ______$ (yearly cost of electricity) X ______ (CUS for DIR of 7%)

\+ ______$ (yearly maintenance cost) X ______ (CUS for DIR of 0%) = ______$

Equation 11. Initial one time ($) procurement cost of a photovoltaic power system = ______W (answer from Equation 4) X ______$/W (photovoltaic module cost) + ______W (answer from Equation 4)

X 0.20 $/W + $60 + ______W (answer from Equation 4) X 1.25 $/W + ______Wh (answer from Equation 8)

X 0.16 $/Wh + ______W (peak inverter size) X 1.16 $/W + $690 = ______$

Equation 12. Installation cost ($) of a photovoltaic power system = ______W (answer from Equation 4) X 17.0 $/W = ______$

Equation 13. Future battery ($) replacement cost = ______Wh (answer from Equation 8) X 0.16 $/Wh = ______$

Equation 14. Operating and maintenance ($/yr) cost of a photovoltaic power system = ______Wh (answer from Equation 8) X 0.001 $/Wh + ______$/trip (personnel cost per trip)

X 2 trip/yr = ______$/yr

Equation 10. Life cycle cost ($) for photovoltaic power system = ______$ (answer from Equation 11) + ______$ (answer from Equation 12) + ______$ (answer from Equation 13)

X ______ (first SA for DIR of 0%) + ______$ (answer from Equation 13) X ______ (second SA for DIR of 0%)

\+ ______$/yr (answer from Equation 14) X ______ (CUS for DIR of 0%) = ______$

Economic module ($/W) cost per watt = ______$ (smallest answer for Equation 10 of conventional power sources) - ______$/yr (answer from Equation 14) X ______ (CUS for DIR of 0%)

\- ______$ (answer from Equation 13) X ______ (first SA for DIR of 0%) - ______$ (answer from Equation 13) X ______ (second SA for DIR of 0%)

\- ______$ (answer from Equation 12) - $690 - ______W (peak inverter watts) X 1.16 $/W - ______Wh (answer from Equation 8)

X 0.16 $/Wh - ______W (answer from Equation 4) X 1.25 $/W - $60 - ______W (answer from Equation 4) X 0.20 $/W

divided by

______W (answer from Equation 4)

= ______$/W

Appendix B

PHOTOVOLTAIC POWER SYSTEM LOAD IDENTIFICATION, SYSTEM SIZING, AND COSTING EXAMPLE

PHOTOVOLTAIC POWER SYSTEM LOAD IDENTIFICATION

1. The enclosed form, "Photovoltaic Power System Requirements," must be accurately completed before a valid assessment can be made as to the feasibility and cost-effectiveness of the proposed application. The following instructions will help to adequately complete the form.

2. **Title**: The title can be any designation that identifies the application.

3. **Location**: Supply name of activity, city, and state. If the application is located remote to the main site area, give a brief description of the location (e.g., mountain-top, desert, valley).

4. **Contact**: Supply name and address of person who will be responsible for the system. This person will be responsible for supplying application requirements and information on operating status. Include the person's business commercial phone number and AUTOVON phone number (if any).

5. **Description of Use**: Supply a brief description of the application. Include the type of equipment to be powered (e.g., electronics, radios, motors) and the present source of power.

6. **Power Requirements**: Supply information on the power requirements of the application. Include voltage requirements (VAC or VDC) and frequency used (e.g., 115 VAC, 60 Hz; 208 VAC, 3-phase, 400 Hz). Supply the application's duty cycles. Include *all* duty cycles. If the application is shut down during part of the year, include that information. For example, if the application is communication equipment, it may have a continuous standby load of 50 watts, a receiving load of 400 watts, and a transmitting load of 800 watts. The application may be in a receiving mode 6 h/day, Monday through Friday, and in a transmitting mode 2 h/day, Monday through Friday. Assuming the application uses 115 VAC, 60 Hz frequency, this example application would be entered as follows:

Power requirements:

System voltage:		________	VDC	115	VAC	60	Hz
Duty cycle:	A	50	watts	24	h/day	7	day/wk
	B	400	watts	6	h/day	5	day/wk
	C	800	watts	2	h/day	5	day/wk
	D	________	watts	________	h/day	________	day/wk

(Power requirements must be as complete and as accurate as possible. The complete power usage must be known so that the photovoltaic power system can be designed properly.)

It is extremely important that accurate power requirements are supplied. A photovoltaic power system can cost as much as $1 for every watthour used by the application in a week depending on location. If a continuous load requirement is overestimated by as little as 10 watts, that is, 10 W x 24 h/day x 7 days/wk x $1/Wh/wk, it will result in an excess cost of $1,680. The best way to determine accurate power requirements is to measure the actual power used by the application. Next best is to use the nameplate power requirements of the application. Guesses and diesel nameplate ratings (if diesels are used) are not acceptable sources for the application power requirements.

7. **Site Information**: Site information such as maximum and minimum temperatures, maximum wind velocity, longitude, latitude, and elevation are all necessary for designing the photovoltaic power systems. Extreme accuracy of these parameters is not necessary, and best guesses are acceptable. Remember that these parameters will be used to design the system, and the system cannot be expected to operate outside of these parameters.

Indicate the amount of land or roof area available for the photovoltaic power system. Indicate any obstructions that would keep the sunlight from reaching these areas (e.g., buildings, mountains, trees). Remember that the sun is lower in the winter and is subject to different obstructions than in the summer. Indicate how long these obstructions would shade the photovoltaic power system area (e.g., will block the sunlight for "x" number of hours or for "x" number of degrees from the horizontal). Indicate any special site considerations. Is the site on an east or west facing hill? If so, what is the angle from south of the hill? Does the photovoltaic power system need any special protection from animals or people? Are there any environmental limitations on how the photovoltaic power system can be installed? Are there any limitations on gaining access to the site? These and other special site considerations will help to determine the photovoltaic power system size and cost. A photograph of the site is very helpful, but not essential.

8. Good applications for photovoltaic power systems are those where the power requirements are 20 kilowatts or less and the site is remote from power lines. Photovoltaic power systems are practical when the present power system's operating and maintenance costs are high. The advantages of photovoltaic power systems are that they (1) provide very clean power both electrically and environmentally, (2) have very low operating and maintenance costs, (3) are reliable, and (4) can be turned on and off remotely with the use of a radio-controlled power switch, allowing placement of electrical equipment where access is difficult. The primary disadvantage is the photovoltaic power system's high capital costs. Photovoltaic power systems are practical where their high capital costs are less than the present power systems operating and maintenance costs.

9. Additional information on photovoltaic power systems or how to fill out the form can be obtained by calling Michael Hall on AUTOVON 437-3411, extension 241, or commercial (619) 939-3411, extension 241.

PHOTOVOLTAIC POWER SYSTEM REQUIREMENTS

TITLE: ____________________

LOCATION: ____________________

____

CONTACT: ____________________

Phone: ____________________

DESCRIPTION OF USE: ____________________

____

____

____

____

POWER REQUIREMENTS: Source of requirements: ____________________

System voltage:		________ VDC		________ VAC		________ Hz
Duty cycle:	A	________ watts		________ h/day		________ day/wk
	B	________ watts		________ h/day		________ day/wk
	C	________ watts		________ h/day		________ day/wk
	D	________ watts		________ h/day		________ day/wk

(Power requirements must be as complete and as accurate as possible. The complete power usage must be known so that the photovoltaic power system can be designed properly.)

SITE INFORMATION: (send picture if possible)

Max. temp. ________ Min. temp. ________ Max. wind ________

Longitude ________ Latitude ________ Elevation ________

Land area available: ____________________

Roof area available: ____________________

Shading considerations: ____________________

Special site considerations: ____________________

____

____

____

____

PHOTOVOLTAIC POWER SYSTEM SIZING AND COSTING EXAMPLE

The following assumptions are used to demonstrate the photovoltaic power system sizing technique as outlined in the text of this report.

Application: range instrumentation site
Application location: Albuquerque, N. Mex.; latitude, 35°0′
Photovoltaic modules used: Appendix C
Nominal battery storage voltage: 120 VDC
Battery storage: lead-acid batteries from Appendix E
Design storage requirement: 5 days storage required
Minimum battery storage temperature: −5°F
Inverter efficiency: 85%

The power requirements (from the example of the Photovoltaic Power System Requirements form) are

duty cycle A = 50 W × 24 h/day = 1200 Wh/day
duty cycle B = 400 W × 6 h/day × 5 day/wk ÷ 7 day/wk = 1714 Wh/day
duty cycle C = 800 W × 2 h/day × 5 day/wk ÷ 7 day/wk = 1143 Wh/day

The load power requirement is calculated by using Equation 1.

$$\text{load (Wh/day)} = \frac{\text{duty cycles (Wh/day)}}{\text{power conditioning efficiency (decimal)}} \tag{1}$$

where

duty cycles (Wh/day) = sum of duty cycles.

power conditioning efficiency (decimal) = from example assumptions.

$$\text{load (Wh/day)} = \frac{1200 \text{ Wh/day} + 1714 \text{ Wh/day} + 1143 \text{ Wh/day}}{0.85} = 4773 \text{ Wh/day}$$

The number of series photovoltaic modules needed for this photovoltaic power system is calculated by using Equation 2.

$$\begin{array}{l}\text{number of series} \\ \text{photovoltaic modules}\end{array} = \frac{\text{nominal battery storage voltage (VDC)}}{\text{nominal photovoltaic module voltage (VDC/module)}} \tag{2}$$

where

nominal battery storage voltage (VDC) = from example assumptions.

nominal photovoltaic module voltage (VDC/module) = specification from Appendix C.

$$\text{number of series photovoltaic modules} = \frac{120 \text{ VDC}}{12 \text{ VDC}} = 10 \text{ photovoltaic modules}$$

Since the load power requirements are constant throughout the year, the photovoltaic array tilt angle will be selected so that the amount of solar radiation received by the array in the winter is as close as possible to the amount received in the summer. The tables in Appendix D will be used, and a choice of three tilt angles is available in the tables. For a tilt angle of latitude minus 15 degrees, the difference between the winter and summer solar radiation received by the array is 3.4 kWh/m^2. For a tilt angle of latitude plus 0 degrees, the difference is 1.5 kWh/m^2; and for a tilt angle of latitude plus 15 degrees, the difference is 0.0 kWh/m^2. The tilt angle of latitude plus 15 degrees is selected since it most closely matches the winter and summer solar radiation received by the array. Equation 3 is now solved for each month, and the largest answer is used in the balance of the array sizing (Table B-1). (Remember that the values of equivalent peak hours per day are the same as the values of the daily solar radiation in kWh/m^2.)

$$\begin{matrix}\text{number of} \\ \text{parallel} \\ \text{photovoltaic} \\ \text{modules}\end{matrix} = \frac{\text{load (Wh/day)} \times 1.20}{\begin{matrix}\text{nominal battery} \\ \text{storage voltage} \\ \text{(VDC)}\end{matrix} \times \begin{matrix}\text{equivalent peak} \\ \text{hours per day} \\ \text{(h/day)}\end{matrix} \times \begin{matrix}\text{nominal photovoltaic} \\ \text{module current} \\ \text{(A/module)}\end{matrix}} \tag{3}$$

where

load (Wh/day) = 4773 Wh/day from example Equation 1.

nominal battery storage voltage (VDC) = from example assumptions.

equivalent peak hours per day (h/day) = from Appendix D.

nominal photovoltaic module current (A/module) = specification from Appendix C.

TABLE B-1. Monthly Results of Equation 3.

	Load (Wh/day)				Nominal battery storage voltage (VDC)		Equivalent peak hours per day (h/day)		Nominal photovoltaic module current (A/module)		Number of parallel photovoltaic modules	
											Calc.	Next higher whole number
Jan	4773	X	1.20	÷	120	÷	6.4	÷	1.2	=	6.21	7
Feb	4773	X	1.20	÷	120	÷	6.8	÷	1.2	=	5.85	6
Mar	4773	X	1.20	÷	120	÷	7.1	÷	1.2	=	5.60	6
Apr	4773	X	1.20	÷	120	÷	6.9	÷	1.2	=	5.76	6
May	4773	X	1.20	÷	120	÷	6.4	÷	1.2	=	6.21	7
Jun	4773	X	1.20	÷	120	÷	6.3	÷	1.2	=	6.31	7
Jul	4773	X	1.20	÷	120	÷	6.2	÷	1.2	=	6.42	7
Aug	4773	X	1.20	÷	120	÷	6.7	÷	1.2	=	5.94	6
Sep	4773	X	1.20	÷	120	÷	7.3	÷	1.2	=	5.45	6
Oct	4773	X	1.20	÷	120	÷	7.3	÷	1.2	=	5.45	6
Nov	4773	X	1.20	÷	120	÷	6.7	÷	1.2	=	5.94	6
Dec	4773	X	1.20	÷	120	÷	6.2	÷	1.2	=	6.42	7 largest answer 7

Equation 4 is used to calculate the total peak watts of photovoltaic modules necessary for the photovoltaic power system.

$$\text{total peak watts (W)} = \begin{array}{c}\text{number of series}\\ \text{photovoltaic}\\ \text{modules}\end{array} \times \begin{array}{c}\text{number of parallel}\\ \text{photovoltaic}\\ \text{modules}\end{array} \times \begin{array}{c}\text{peak watts per}\\ \text{photovoltaic}\\ \text{module (W)}\end{array} \qquad (4)$$

where

number of series photovoltaic modules = answer from example Equation 2.

number of parallel photovoltaic modules = largest answer from example Equation 3.

peak watts per photovoltaic module (W) = specification from Appendix C.

$$\text{total peak watts (W)} = 10 \times 7 \times 20 \text{ W} = 1400 \text{ W}$$

Battery storage sizing will be illustrated by continuing the example. The designed battery storage size is found by solving Equation 5 for each month and using the largest answer for the balance of the battery storage sizing (Table B-2).

$$\text{designed battery storage size (Wh)} = \frac{\text{load (Wh/day)} \times 1.20 \times \text{required days of storage (day)}}{\text{depth of discharge (decimal)}} \qquad (5)$$

where

load (Wh/day) = answer from example Equation 1.

required days of storage (day) = from example assumptions.

depth of discharge (decimal) = from Figure 8.

TABLE B-2. Monthly Results of Equation 5.

	Load (Wh/day)				Required days of storage (day)		Depth of Discharge (decimal)		Designed battery storage size (Wh)
Jan	4773	X	1.20	X	5	÷	0.63	=	45457
Feb	4773	X	1.20	X	5	÷	.56	=	51139
Mar	4773	X	1.20	X	5	÷	.76	=	37682
Apr	4773	X	1.20	X	5	÷	.80	=	35798
May	4773	X	1.20	X	5	÷	.80	=	35798
Jun	4773	X	1.20	X	5	÷	.80	=	35798
Jul	4773	X	1.20	X	5	÷	.80	=	35798
Aug	4773	X	1.20	X	5	÷	.80	=	35798
Sep	4773	X	1.20	X	5	÷	.80	=	35798
Oct	4773	X	1.20	X	5	÷	.80	=	35798
Nov	4773	X	1.20	X	5	÷	.79	=	36251
Dec	4773	X	1.20	X	5	÷	0.68	=	42115
									largest answer 51139

The number of series-connected batteries is computed by using Equation 6.

$$\text{number of series batteries} = \frac{\text{nominal battery storage voltage (VDC)}}{\text{nominal single battery voltage (VDC/battery)}} \tag{6}$$

where

nominal battery storage voltage (VDC) = from example assumptions.

nominal single battery voltage (VDC/battery) = specification from Appendix E.

$$\text{number of series batteries} = \frac{120 \text{ VDC}}{6 \text{ VDC/battery}} = 20 \text{ batteries}$$

The number of parallel-connected batteries is computed by using Equation 7.

$$\text{number of parallel batteries} = \frac{\text{designed battery storage size (Wh)}}{\text{nominal battery storage voltage (VDC)} \times \text{nominal ampere hours per battery (Ah/battery)}} \qquad (7)$$

where

designed battery storage size (Wh) = largest answer from example Equation 5.

nominal battery storage voltage (VDC) = from example assumptions.

nominal ampere hours per battery (Ah/battery) = specification from Appendix E.

$$\text{number of parallel batteries} = \frac{51{,}139 \text{ Wh}}{120 \text{ VDC} \times 200 \text{ Ah/battery}} = \text{2.13 batteries (rounded to next higher whole number)} = 3 \text{ batteries}$$

The actual battery storage size is computed by using Equation 8.

$$\text{actual battery storage size (Wh)} = \text{number of series batteries} \times \text{number of parallel batteries} \times \text{nominal ampere hours per battery (Ah)} \times \text{nominal single battery voltage (VDC)} \qquad (8)$$

where

number of series batteries = answer from example Equation 6.

number of parallel batteries = answer from example Equation 7.

nominal ampere hours per battery (Ah) = specification from Appendix E.

nominal single battery voltage (VDC) = specification from Appendix E.

$$\text{actual battery storage size (Wh)} = 20 \times 3 \times 200 \text{ Ah} \times 6 \text{ VDC} = \text{72,000 Wh (divided by 1000 to convert to kilowatthours)} = 72 \text{ kWh}$$

The ability of the battery storage to supply the peak battery current requirement of the load is determined as discussed in the text.

Step 1. Solve Equation 9.

$$\text{peak battery current requirement (A)} = \frac{\text{peak load power requirement (W)}}{\text{nominal battery storage voltage (VDC)} \times \text{number of parallel batteries}} \qquad (9)$$

where

peak load power requirement (W) = largest duty cycle (from the example of the Photovoltaic Power System Requirements form assumptions) = 800 W ÷ 0.85 = 941 W.

nominal battery storage voltage (VDC) = from example assumptions.

number of parallel batteries = answer from example Equation 7.

$$\text{peak battery current requirement (A)} = \frac{941\ \text{W}}{120\ \text{VDC} \times 3} = 2.61\ \text{A}$$

Step 2. From the battery design curve in Appendix E, the battery storage can supply 2.61 amperes for about 50 hours at a minimum operating temperature of −5°F.

Step 3. The peak load duty cycle is 2 h/day. The battery storage must supply 2.61 amperes for 2 h/day times 5 days required storage, or 10 hours. The battery storage can meet this requirement and is therefore properly designed.

The economic analysis procedures are illustrated using the example. The following additional information is assumed.

Diesel generators cost 500 \$/kW.

Storage tank costs 200 \$.

Diesel maintenance costs consist of diesel maintenance and fuel delivery requiring 3 men 8 h/day 1 day/month at a cost of 20 \$/h for a total of 5760 \$/yr.

Operating costs are computed as follows: The load uses 4057 Wh/day (from the duty cycles of example Equation 1). The diesel generators use 0.0756 gallon of fuel to produce 1000 Wh of electricity. Diesel fuel costs 0.70 \$/gal. The operating cost is 4057 Wh/day × 365 day/yr × 0.0756 gal/1000 Wh × 0.70 \$/gal which equals 78.36 \$/yr.

Peak load is 800 watts.

Battery power source size is computed from Equation 5 using the worst case (smallest) depth of discharge and a required days of storage equal to 7. From example Equation 5,

$$\text{battery power source size (Wh)} = \frac{4773\ \text{Wh/day} \times 1.20 \times 7\ \text{day}}{0.56} = 71{,}595\ \text{Wh}$$

Battery power source cost is 0.16 \$/Wh, which equals 71,595 Wh × 0.16 \$/Wh = 11,455 \$.

Battery replacement costs are also 11,455 \$.

Battery maintenance cost requires battery recharging once a week. Recharging requires 2 men, 8 h/day, 1 day/wk, 52 wk/yr, at 25 \$/h, for a total of 20,800 \$/yr.

Battery operating cost is the cost of the electricity to recharge the batteries. Electricity cost is assumed at 0.06 \$/kWh. The load uses 4773 Wh/day from the battery power source (example Equation 1). The battery operating cost is 4773 Wh/day × 365 day/yr ÷ 1000 Wh/kWh × 0.06 \$/kWh = 104.53 \$/yr.

Cost of extending an existing utility grid is 30,000 \$/mi. The application site is 15 miles from the nearest utility grid. The utility grid extension cost equals 30,000 \$/mi × 15 miles = 450,000 \$.

The utility grid maintenance costs are assumed at 1000 \$/yr.

The operating cost equals the energy used times the electricity cost that equals 4057 Wh/day × 365 day/yr ÷ 1000 Wh/kWh × 0.06 \$/kWh = 88.85 \$/yr.

Photovoltaic module cost per watt is assumed at 15 \$/W.

Personnel transportation cost per trip equals 25 \$/h × 2 persons × 4 hours, which equals 200 \$/trip.

Once the assumptions have been identified, the life-cycle costs of the three conventional power sources can be calculated from Equation 10, and the life-cycle cost of the photovoltaic power system can be calculated with Equations 10-14.

$$\begin{aligned} \begin{matrix}\text{life-cycle cost}\\ \text{(present value) (\$)}\end{matrix} &= \begin{matrix}\text{initial one-}\\ \text{time cost (\$)}\end{matrix} + \begin{matrix}\text{future one-}\\ \text{time cost (\$)}\end{matrix} \times \begin{matrix}\text{single-amount}\\ \text{discount factor}\end{matrix} \\ &+ \begin{matrix}\text{equal recurring}\\ \text{yearly costs (\$)}\end{matrix} \times \begin{matrix}\text{cumulative-uniform-}\\ \text{series discount factor}\end{matrix} \qquad (10) \end{aligned}$$

The life-cycle cost for the diesel generator power source is calculated by using Equation 10

where

initial one-time cost (\$) = diesel generators cost + fuel storage cost = 500 \$/kW × 800 W ÷ 1000 W/kW + 200 \$ = 600 \$.

future one-time cost (\$) = 0 \$.

equal recurring yearly costs (\$) = operating and maintenance costs = 78.36 \$ and 5760 \$ respectively.

cumulative-uniform-series discount factor = that obtained from Appendix F:

Differential Inflation Rate of 0% for 25 years = 9.524.
Differential Inflation Rate of 8% for 25 years = 20.050.

Equation 10 for diesel generator power source now reads

$$\begin{array}{c}\text{life-cycle cost}\\ \text{(present value) (\$)}\end{array} = 600\ \$ + 78.36\ \$ \times 20.050 + 5760\ \$ \times 9.524 = 57{,}029.36\ \$$$

The life-cycle cost for the battery power source is calculated by using Equation 10

where

initial one-time cost (\$) = 11,455 \$.

future one-time cost (\$) = 11,455 \$.

single-amount discount factor = that obtained from Appendix F:

Differential Inflation Rate of 0% for year 10 = 0.405.
Differential Inflation Rate of 0% for year 20 = 0.156.

equal recurring yearly costs (\$) = 20,800 \$ and 104.53 \$.

cumulative-uniform-series discount factor = that obtained from Appendix F:

Differential Inflation Rate of 0% for 25 years = 9.524.
Differential Inflation Rate of 7% for 25 years = 18.049.

Equation 10 for battery power source now reads

$$\begin{array}{c}\text{life-cycle cost}\\ \text{(present value) (\$)}\end{array} = 11{,}455\ \$ + 11{,}455\ \$ \times 0.405 + 11{,}455\ \$ \times 0.156 + 20{,}800\ \$$$

$$\times\ 9.524 + 104.53\ \$ \times 18.049 = 217{,}867.12\ \$$$

The life-cycle cost for the utility grid extension power source is calculated by using Equation 10

where

initial one-time cost (\$) = 450,000 \$.

future one-time cost (\$) = 0 \$.

equal recurring yearly costs (\$) = 1000 \$ and 88.85 \$.

cumulative-uniform-series discount factor = that obtained from Appendix F:

Differential Inflation Rate of 0% for 25 years = 9.524.
Differential Inflation Rate of 7% for 25 years = 18.049.

Equation 10 for utility grid extension power source now reads

$$\begin{array}{c}\text{life-cycle cost}\\ \text{(present value) (\$)}\end{array} = 450{,}000\ \$ + 1000\ \$ \times 9.524 + 88.85\ \$ \times 18.049 = 461{,}127.65\ \$$$

The life-cycle cost of the photovoltaic power system is calculated by using Equation 10. The values to be used in Equation 10 are calculated by using Equations 11-14.

$$\begin{array}{c}\text{initial one-time}\\ \text{procurement cost}\\ \text{of a photovoltaic}\\ \text{power system (\$)}\end{array} = \begin{array}{c}\text{total peak}\\ \text{watts (W)}\end{array} \times \begin{array}{c}\text{photovoltaic module}\\ \text{cost per watt (\$/W)}\end{array} + \begin{array}{c}\text{total peak}\\ \text{watts (W)}\end{array} \times 0.20\ (\$/\text{W})$$

$$+ 60\ (\$) + \begin{array}{c}\text{total peak}\\ \text{watts (W)}\end{array} \times 1.25\ (\$/\text{W}) + \begin{array}{c}\text{actual battery}\\ \text{storage size (Wh)}\end{array}$$

$$\times 0.16\ (\$/\text{Wh}) + \begin{array}{c}\text{total peak}\\ \text{inverter watts (W)}\end{array} \times 1.16\ (\$/\text{W}) + 690\ (\$) \qquad (11)$$

where

total peak watts (W) = answer from example Equation 4.

photovoltaic module cost per watt (\$/W) = from cost assumptions.

actual battery storage size (Wh) = answer from example Equation 8.

total peak inverter watts (W) = from cost assumptions.

Equation 11 now reads

$$\begin{array}{c}\text{initial one-time}\\ \text{procurement cost}\\ \text{of a photovoltaic}\\ \text{power system (\$)}\end{array} = 1400\ \text{W} \times 15\ \$/\text{W} + 1400\ \text{W} \times 0.20\ \$/\text{W} + 60\ \$ + 1400\ \text{W}$$

$$\times 1.25\ \$/\text{W} + 72{,}000\ \text{Wh} \times 0.16\ \$/\text{Wh} + 800\ \text{W} \times 1.16\ \$/\text{W} + 690\ \$ = 36{,}228\ \$$$

$$\begin{array}{c}\text{installation cost of a}\\ \text{photovoltaic power system (\$)}\end{array} = \begin{array}{c}\text{total peak}\\ \text{watts (W)}\end{array} \times 17.0\ (\$/\text{W}) = 1400\ \text{W} \times 17.0\ \$/\text{W}$$

$$= 23{,}800\ \$ \qquad (12)$$

The initial one-time cost is the sum of Equations 11 and 12.

$$\text{initial one-time cost (\$)} = 36{,}228\ \$ + 23{,}800\ \$ = 60{,}028\ \$$$

The future one-time cost is the future battery replacement cost and is calculated by using Equation 13.

$$\begin{matrix}\text{future one-}\\ \text{time cost (\$)}\end{matrix} = \begin{matrix}\text{actual battery}\\ \text{storage size (Wh)}\end{matrix} \times 0.16\ (\$/\text{Wh}) = 72{,}000\ \text{Wh} \times 0.16\ \$/\text{Wh}$$

$$= 11{,}520\ \$ \qquad (13)$$

The single-amount discount factor is obtained from Appendix F for the proper Differential Inflation Rate:

Differential Inflation Rate of 0% for year 10 = 0.405.
Differential Inflation Rate of 0% for year 20 = 0.156.

The equal recurring yearly costs are the operating and maintenance costs of a photovoltaic power system and are calculated by using Equation 14.

$$\begin{matrix}\text{equal recurring}\\ \text{yearly costs (\$)}\end{matrix} = \begin{matrix}\text{actual battery}\\ \text{storage size (Wh)}\end{matrix} \times 0.001\ (\$/\text{Wh}) + \begin{matrix}\text{personnel}\\ \text{transportation}\\ \text{costs per trip (\$/trip)}\end{matrix}$$

$$\times\ 2\ (\text{trips/yr}) = 72{,}000\ \text{Wh} \times 0.001\ \$/\text{Wh} + 200\ \$/\text{trip} \times 2\ \text{trips/yr}$$

$$= 472\ \$ \qquad (14)$$

The cumulative-uniform-series discount factor is obtained from Appendix F for the proper Differential Inflation Rate:

Differential Inflation Rate of 0% for 25 years = 9.524.

When the answers from Equations 11-14 are substituted into Equation 10, the life-cycle cost for the photovoltaic power system reads as follows:

$$\begin{matrix}\text{life-cycle cost}\\ \text{(present value) (\$)}\end{matrix} = 60{,}028\ \$ + 11{,}520\ \$ \times 0.405 + 11{,}520\ \$ \times 0.156 + 472\ \$$$

$$\times\ 9.524 = 70{,}986.05\ \$$$

Comparing the life-cycle costs of the four power systems shows that the diesel generator is the most cost-effective with the photovoltaic power system being second most cost-effective. The economic module cost will now be calculated for this example. The lowest life-cycle cost of the three conventional power sources is the 57,029.36 $ for the diesel generator power source.

This is the life-cycle cost that the photovoltaic power system must have to become cost-effective. When the 57,029.36 \$ is substituted into example Equation 10 for the photovoltaic power system, the cost-effective initial one-time cost can be calculated as follows:

$$57{,}029.36\ \$ = \frac{\text{initial one-}}{\text{time cost (\$)}} + 11{,}520\ \$ \times 0.405 + 11{,}520\ \$ \times 0.156 + 472\ \$$$

$$\times\ 9.524 = \frac{\text{initial one-}}{\text{time cost (\$)}} + 10{,}958.05\ \$$$

Solving for initial one-time cost (\$) gives

$$\text{initial one-time cost (\$)} = 57{,}029.36\ \$ - 10{,}958.05\ \$ = 46{,}071.31\ \$$$

$$\text{initial one-time cost (\$)} = \text{example Equation 11} + \text{example Equation 12}$$

Substituting in the values for the initial one-time cost and example Equation 12 gives

$$46{,}071.31\ \$ = \text{example Equation 11} + 23{,}800\ \$$$

Solving for example Equation 11 gives

$$\text{example Equation 11} = 46{,}071.31\ \$ - 23{,}800\ \$ = 22{,}271.31\ \$$$

$$\text{example Equation 11} = 1400\ \text{W} \times \frac{\text{photovoltaic module}}{\text{cost per watt (\$/W)}} + 1400\ \text{W} \times 0.20\ \$/\text{W}$$

$$+\ 60\ \$ + 1400\ \text{W} \times 1.25\ \$/\text{W} + 72{,}000\ \text{Wh} \times 0.16\ \$/\text{Wh} + 800\ \text{W}$$

$$\times\ 1.16\ \$/\text{W} + 690\ \$ = 1400\ \text{W} \times \frac{\text{photovoltaic module}}{\text{cost per watt (\$/W)}} + 15{,}228\ \$$$

Substituting in the value of example Equation 11 gives

$$22{,}271.31\ \$ = 1400\ \text{W} \times \frac{\text{photovoltaic module}}{\text{cost per watt (\$/W)}} + 15{,}228\ \$$$

Solving for the photovoltaic module cost per watt gives the economic module cost.

$$\begin{matrix}\text{photovoltaic module}\\ \text{cost per watt (\$/W)}\end{matrix} = \frac{22{,}271.31\ \$ - 15{,}228\ \$}{1400\ \text{W}}$$

thus

$$\text{economic module cost (\$/W)} = 5.03\ \$/\text{W}$$

Figure 10 shows when the Navy should be able to procure photovoltaic modules through contracts for 5.03 $/W. The photovoltaic power system in this example should be cost-effective and should be purchased by the Navy in 1985.

Appendix C

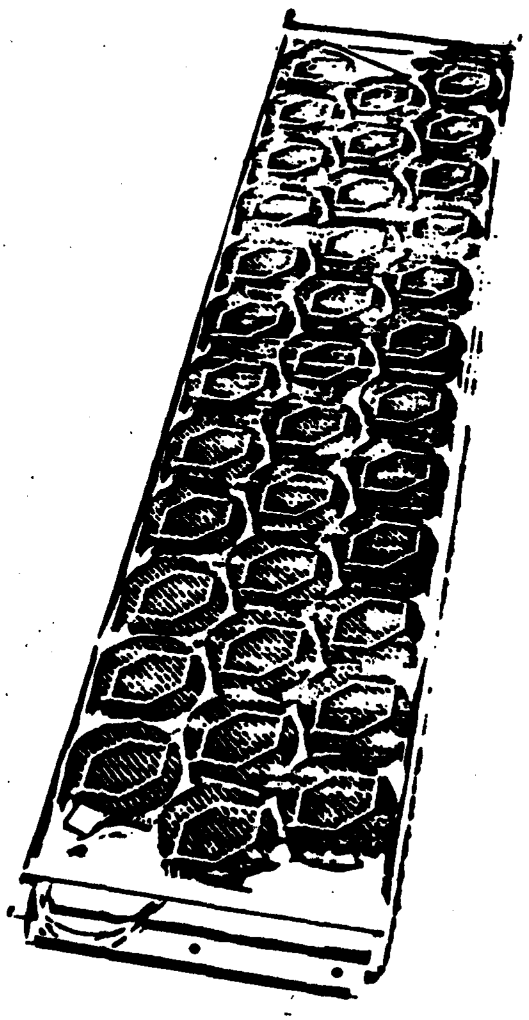
PHOTOVOLTAIC MODULE SPECIFICATION SHEET

Specifications

The Module:

Nominal Voltage: 12 VDC
Min. Test Voltage: 16.2 VDC
Test Current: 1.2 Amps
Typical Short Circuit Current: 1.3 Amps
Typical Open Circuit Voltage: 20.0 VDC
Peak Power: 20 Watts
Weight: 7.3 lbs., 3.3 kg.

Note: Power outputs shown are under Standard Test Conditions of 100 mw/cm² and 28°C. temperature.



Appendix D

AVERAGE DAILY SOLAR INSOLATION TABLES[1]

[1] Jet Propulsion Laboratory. *A Handbook of Solar Energy Data for Surfaces of Arbitrary Orientation in the United States and Canada*, by J. H. Smith. Pasadena, Calif., JPL, September 1979. (JPL Document 5101-91, document UNCLASSIFIED.)

INSOLATION

(kWh/m²)

Location: Abilene, TX Latitude: 32° 20'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.2	4.7	5.0
F	5.1	5.5	5.6
M	5.9	6.0	5.8
A	6.4	6.2	5.7
M	6.6	6.1	5.4
J	7.2	6.6	5.6
J	6.8	6.3	5.5
A	6.7	6.5	5.9
S	6.1	6.2	6.0
O	5.3	5.7	5.8
N	4.2	4.8	5.1
D	3.8	4.4	4.7

Location: Albany, NY Latitude: 42° 40'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.2	2.4	2.5
F	2.9	3.1	3.1
M	5.1	5.2	5.0
A	4.6	4.4	4.0
M	5.1	4.7	4.2
J	6.8	6.1	5.3
J	6.1	5.6	4.9
A	5.3	5.1	4.7
S	4.0	4.1	3.9
O	3.9	4.1	4.2
N	4.0	4.6	4.9
D	2.6	3.0	3.2

Location: Albuquerque, NM Latitude: 35° 0'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	5.2	6.0	6.4
F	6.1	6.7	6.8
M	7.2	7.4	7.1
A	7.8	7.6	6.9
M	8.0	7.3	6.4
J	8.2	7.4	6.3
J	7.8	7.2	6.2
A	7.6	7.3	6.7
S	7.3	7.5	7.3
O	6.5	7.1	7.3
N	5.4	6.3	6.7
D	4.8	5.7	6.2

Location: Amarillo, TX Latitude: 35° 10'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.7	5.4	5.8
F	5.6	6.1	6.2
M	6.3	6.4	6.2
A	7.1	6.8	6.2
M	7.1	6.5	5.7
J	7.4	6.7	5.7
J	7.2	6.6	5.8
A	7.1	6.9	6.3
S	6.5	6.6	6.4
O	5.7	6.2	6.4
N	4.9	5.6	6.0
D	4.3	5.0	5.5

INSOLATION

(kWh/m^2)

Location: Ames, IA Latitude: 42° 0'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.4	3.8	4.0
F	4.3	4.6	4.7
M	4.8	4.8	4.7
A	5.1	4.9	4.5
M	5.6	5.1	4.5
J	6.1	5.5	4.8
J	6.1	5.6	4.9
A	5.6	5.3	4.9
S	4.9	4.9	4.7
O	4.2	4.5	4.5
N	3.3	3.7	3.9
D	2.7	3.0	3.2

Location: Amherst, MA Latitude: 42° 10'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.0	2.2	2.3
F	2.9	3.0	3.0
M	4.4	4.4	4.2
A	4.4	4.2	3.8
M	5.0	4.6	4.1
J	5.8	5.2	4.5
J	5.9	5.4	4.7
A	5.2	5.0	4.6
S	4.3	4.4	4.2
O	3.7	4.0	4.0
N	2.6	2.9	3.0
D	2.2	2.5	2.7

Location: Annapolis, MD Latitude: 38° 60'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.9	3.3	3.4
F	3.8	4.0	4.1
M	4.7	4.8	4.6
A	5.3	5.1	4.7
M	5.7	5.3	4.6
J	6.2	5.6	4.9
J	6.1	5.6	4.9
A	5.6	5.4	4.9
S	4.9	5.0	4.8
O	4.2	4.5	4.5
N	2.9	3.3	3.4
D	2.6	3.0	3.1

Location: Annette, AK Latitude: 55° 0'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	1.9	2.2	2.3
F	2.7	2.8	2.8
M	4.3	4.4	4.2
A	5.2	5.0	4.5
M	5.3	4.8	4.2
J	5.0	4.5	3.9
J	5.0	4.6	4.0
A	4.3	4.1	3.7
S	3.9	3.9	3.8
O	2.2	2.3	2.3
N	1.4	1.5	1.6
D	1.2	1.4	1.5

INSOLATION

(kWh/m^2)

Location: Apalachicola, FL   Latitude: 29° 40'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.2	4.7	5.0
F	5.1	5.5	5.6
M	5.8	5.9	5.7
A	6.7	6.4	5.9
M	6.9	6.4	5.6
J	6.7	6.1	5.2
J	6.2	5.7	5.0
A	5.9	5.7	5.2
S	5.6	5.7	5.5
O	5.4	5.9	6.0
N	4.6	5.2	5.5
D	3.7	4.3	4.6

Location: Asheville, NC   Latitude: 35° 30'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.5	3.9	4.[illegible]
F	4.5	4.8	4.8
M	5.2	5.3	5.1
A	6.1	5.9	5.4
M	6.4	5.9	5.2
J	6.4	5.8	5.0
J	6.3	5.8	5.1
A	6.0	5.8	5.3
S	5.5	5.6	5.4
O	5.0	5.4	5.5
N	3.8	4.3	4.5
D	3.2	3.7	3.9

Location: Astoria, OR   Latitude: 46° 10'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	1.8	1.9	2.0
F	2.7	2.9	2.9
M	4.1	4.1	3.9
A	4.9	4.7	4.2
M	5.8	5.3	4.6
J	5.4	4.9	4.3
J	6.1	5.6	4.9
A	5.6	5.4	4.9
S	5.0	5.0	4.8
O	3.4	3.6	3.6
N	2.0	2.2	2.3
D	1.5	1.6	1.7

Location: Atlanta, GA   Latitude: 33° 40'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.5	3.9	4.1
F	4.1	4.4	4.5
M	5.1	5.1	5.0
A	5.9	5.7	5.2
M	6.1	5.6	5.0
J	6.2	5.6	4.9
J	6.1	5.6	5.0
A	5.8	5.6	5.2
S	5.1	5.2	5.0
O	4.7	5.1	5.2
N	3.8	4.3	4.6
D	3.0	3.5	3.7

INSOLATION

(kWh/m²)

Location: Atlantic City, NJ   Latitude: 39° 30'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.1	3.4	3.6
F	4.0	4.3	4.4
M	5.6	5.7	5.5
A	5.4	5.2	4.7
M	5.7	5.2	4.6
J	6.4	5.8	5.1
J	6.4	5.9	5.2
A	5.7	5.5	5.0
S	5.1	5.2	5.0
O	4.4	4.8	4.9
N	3.5	3.9	4.1
D	2.7	3.1	3.3

Location: Baltimore, MD   Latitude: 39° 10'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.0	3.4	3.5
F	3.9	4.1	4.2
M	4.8	4.9	4.7
A	5.3	5.1	4.6
M	5.7	5.2	4.6
J	6.2	5.6	4.9
J	6.1	5.6	4.9
A	5.6	5.4	4.9
S	4.9	5.0	4.8
O	4.3	4.6	4.6
N	3.0	3.3	3.5
D	2.7	3.0	3.2

Location: Bethel, AK   Latitude: 60° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	1.9	2.1	2.2
F	3.7	4.0	4.1
M	6.6	6.8	6.6
A	7.2	6.9	6.3
M	5.7	5.2	4.5
J	5.1	4.6	3.9
J	4.2	3.8	3.3
A	3.2	3.0	2.7
S	3.1	3.2	3.0
O	2.7	3.0	3.0
N	1.6	1.8	1.9
D	1.3	1.5	1.6

Location: Big Spring, TX   Latitude: 32° 10'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.1	4.6	4.9
F	5.0	5.3	5.4
M	6.2	6.4	6.2
A	7.2	6.9	6.3
M	6.5	6.0	5.3
J	6.7	6.1	5.2
J	6.2	5.7	5.0
A	5.4	5.2	4.8
S	6.5	6.7	6.4
O	5.2	5.6	5.7
N	4.2	4.7	5.0
D	4.0	4.6	4.9

INSOLATION

(kWh/m²)

Location: Billings, MT Latitude: 45° 50'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.4	3.9	4.1
F	4.5	4.8	4.9
M	5.6	5.8	5.6
A	6.0	5.8	5.2
M	6.3	5.8	5.1
J	6.9	6.2	5.4
J	7.4	6.8	5.9
A	7.0	6.7	6.[illegible]
S	6.0	6.2	6.0
O	4.1	4.2	4.5
N	3.4	3.8	4.1
D	2.8	3.3	3.5

Location: Binghampton, NY Latitude: 42° 10'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.5	2.8	2.9
F	3.4	3.6	3.6
M	4.4	4.4	4.2
A	4.8	4.6	4.2
M	5.7	5.2	4.6
J	6.2	5.6	4.9
J	6.2	5.7	5.0
A	5.7	5.4	5.0
S	4.8	4.9	4.7
O	3.9	4.2	4.2
N	2.3	2.6	2.7
D	2.0	2.3	2.4

Location: Birmingham, AL Latitude: 33° 30'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.1	3.4	3.6
F	4.1	4.3	4.4
M	4.9	4.9	4.8
A	6.0	5.8	5.3
M	6.4	5.9	5.2
J	6.3	5.7	4.9
J	6.2	5.7	5.0
A	5.9	5.7	5.2
S	5.3	5.4	5.2
O	4.8	5.2	5.3
N	3.5	3.9	4.2
D	2.9	3.3	3.5

Location: Bismarck, ND Latitude: 46° 50'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.6	4.1	4.3
F	4.9	5.3	5.4
M	5.6	5.7	5.6
A	6.0	5.7	5.2
M	6.6	6.0	5.3
J	6.6	5.9	5.1
J	7.0	6.4	5.6
A	6.4	6.1	5.6
S	5.4	5.5	5.3
O	4.6	5.0	5.1
N	3.2	3.6	3.8
D	2.8	3.2	3.5

INSOLATION

(kWh/m^2)

Location: Blue Hill, MA Latitude: 42° 10'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.9	3.2	3.4
F	3.6	3.8	3.8
M	4.5	4.5	4.3
A	4.8	4.6	4.2
M	5.4	5.0	4.4
J	5.8	5.2	4.5
J	5.7	5.2	4.6
A	5.2	5.0	4.6
S	4.6	4.7	4.5
O	3.7	4.0	4.0
N	2.6	2.9	3.1
D	2.4	2.7	2.9

Location: Boise, ID Latitude: 43° 30'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.7	3.1	3.2
F	4.1	4.4	4.4
M	5.1	5.1	5.0
A	6.4	6.1	5.6
M	6.9	6.4	5.5
J	7.2	6.5	5.6
J	7.7	7.1	6.1
A	7.0	6.7	6.1
S	6.3	6.5	6.2
O	5.1	5.5	5.6
N	3.3	3.7	3.9
D	2.3	2.6	2.8

Location: Boston, MA Latitude: 42° 20'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.5	2.8	2.9
F	3.2	3.4	3.4
M	4.3	4.3	4.1
A	4.6	4.4	4.0
M	5.4	5.0	4.4
J	5.5	5.0	4.4
J	5.7	5.2	4.6
A	5.1	4.9	4.5
S	4.4	4.5	4.3
O	3.5	3.8	3.8
N	2.4	2.7	2.8
D	2.2	2.4	2.6

Location: Boulder, CO Latitude: 40° 0'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.7	4.2	4.4
F	4.4	4.7	4.8
M	5.9	6.0	5.8
A	5.8	5.6	5.1
M	5.3	4.9	4.3
J	5.9	5.3	4.6
J	5.9	5.4	4.8
A	5.2	5.0	4.6
S	5.4	5.5	5.3
O	4.6	5.0	5.1
N	3.8	4.3	4.5
D	3.4	3.9	4.2

INSOLATION

(kWh/m^2)

Location: Brownsville, TX   Latitude: 25° 50'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.8	4.3	4.5
F	4.4	4.7	4.7
M	5.0	5.1	4.9
A	5.5	5.3	4.9
M	6.4	5.9	5.2
J	6.8	6.2	5.4
J	7.0	6.5	5.7
A	6.4	6.2	5.7
S	5.6	5.7	5.5
O	5.1	5.5	5.6
N	3.6	4.0	4.2
D	3.3	3.7	3.9

Location: Cape Hatteras, NC   Latitude: 35° 20'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.0	4.5	4.8
F	4.8	5.2	5.3
M	6.0	6.1	5.9
A	7.1	6.8	6.2
M	7.3	6.7	5.9
J	7.3	6.6	5.6
J	7.1	6.5	5.7
A	6.6	6.3	5.8
S	6.0	6.2	5.9
O	5.1	5.5	5.6
N	4.4	5.0	5.3
D	3.4	3.9	4.2

Location: Caribou, ME   Latitude: 46° 50'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.0	3.4	3.6
F	4.4	4.8	4.8
M	6.0	6.1	5.9
A	5.3	5.1	4.6
M	5.5	5.1	4.5
J	5.4	4.9	4.3
J	5.8	5.3	4.6
A	5.5	5.3	4.8
S	4.6	4.7	4.5
O	3.4	3.6	3.6
N	1.9	2.1	2.2
D	2.3	2.6	2.8

Location: Charleston, SC   Latitude: 32° 50'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.8	4.3	4.5
F	4.4	4.7	4.7
M	5.2	5.3	5.1
A	6.3	6.1	5.6
M	6.3	5.8	5.1
J	6.3	5.7	4.9
J	5.9	5.4	4.8
A	5.8	5.6	5.2
S	5.0	5.1	4.9
O	4.6	4.9	5.0
N	4.1	4.7	4.9
D	3.2	3.7	3.9

INSOLATION

(kWh/m^2)

Location: Charlotte, NC Latitude: 35° 10'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.6	4.0	4.2
F	4.5	4.8	4.9
M	5.2	5.3	5.1
A	6.3	6.1	5.6
M	6.3	5.8	5.1
J	6.5	5.9	5.1
J	6.4	5.9	5.2
A	6.2	5.9	5.4
S	5.5	5.6	5.4
O	5.0	5.4	5.5
N	3.8	4.3	4.5
D	3.2	3.7	3.9

Location: Chattanooga, TN Latitude: 35° 0'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.0	3.4	3.5
F	4.0	4.3	4.3
M	4.6	4.7	4.5
A	5.8	5.5	5.1
M	6.2	5.7	5.0
J	6.3	5.7	4.9
J	6.2	5.7	5.0
A	5.9	5.7	5.2
S	5.4	5.5	5.3
O	4.6	5.0	5.0
N	3.3	3.7	3.9
D	2.8	3.1	3.3

Location: Chicago, IL Latitude: 41° 60'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.2	3.6	3.8
F	3.8	4.1	4.1
M	4.8	4.8	4.7
A	4.9	4.7	4.3
M	5.8	5.3	4.7
J	6.2	5.6	4.9
J	6.0	5.5	4.9
A	5.9	5.7	5.2
S	5.1	5.1	4.9
O	4.0	4.3	4.3
N	2.6	2.9	3.0
D	2.3	2.6	2.8

Location: Cleveland, OH Latitude: 41° 20'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.1	2.3	2.4
F	2.8	3.0	3.0
M	4.5	4.5	4.4
A	4.7	4.5	4.1
M	6.1	5.6	4.9
J	6.3	5.7	4.9
J	6.2	5.7	5.0
A	5.9	5.7	5.2
S	5.0	5.0	4.8
O	3.9	4.2	4.2
N	2.2	2.5	2.6
D	1.9	2.2	2.3

INSOLATION

(kWh/m^2)

Location: Columbia, MO   Latitude: 38° 60'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.0	3.4	3.5
F	3.9	4.1	4.2
M	4.8	4.9	4.7
A	5.4	5.2	4.8
M	6.1	5.7	5.0
J	6.4	5.8	5.0
J	6.5	6.0	5.3
A	6.2	6.0	5.5
S	5.9	6.0	5.8
O	4.7	5.1	5.2
N	3.5	4.0	4.2
D	2.9	3.3	3.5

Location: Columbus, OH   Latitude: 40° 0'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.2	2.4	2.4
F	3.1	3.3	3.3
M	4.2	4.3	4.1
A	5.0	4.8	4.3
M	5.7	5.2	4.6
J	6.3	5.7	4.9
J	6.1	5.6	4.9
A	5.7	5.5	5.0
S	5.5	5.6	5.4
O	4.3	4.6	4.6
N	2.9	3.2	3.4
D	2.3	2.6	2.7

Location: Corpus Christi, TX   Latitude: 27° 50'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.6	4.0	4.2
F	4.4	4.7	4.8
M	5.3	5.4	5.2
A	5.7	5.5	5.1
M	6.4	5.9	5.2
J	6.9	6.2	5.4
J	7.1	6.6	5.8
A	6.5	6.3	5.8
S	5.6	5.7	5.5
O	5.2	5.6	5.7
N	3.7	4.2	4.4
D	3.2	3.6	3.8

Location: Corvallis, OR   Latitude: 44° 30'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	1.8	2.0	2.1
F	2.3	2.4	2.3
M	4.2	4.2	4.1
A	5.2	5.0	4.6
M	6.0	5.5	4.8
J	6.5	5.9	5.1
J	7.7	7.1	6.1
A	6.8	6.5	5.9
S	5.5	5.6	5.4
O	3.6	3.9	3.9
N	2.5	2.7	2.9
D	1.4	1.5	1.6

INSOLATION

(kWh/m^2)

Location: Dallas, TX Latitude: 32° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.4	3.8	4.0
F	4.5	4.8	4.8
M	5.2	5.3	5.1
A	5.6	5.4	4.9
M	6.0	5.6	4.9
J	6.7	6.1	5.3
J	6.6	6.1	5.4
A	6.3	6.1	5.5
S	5.7	5.8	5.6
O	4.9	5.2	5.3
N	3.7	4.2	4.4
D	3.3	3.8	4.0

Location: Davis, CA Latitude: 38° 30'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.6	2.9	3.0
F	4.0	4.2	4.3
M	5.7	5.8	5.6
A	6.7	6.5	5.9
M	7.3	6.7	5.9
J	7.8	7.1	6.0
J	7.9	7.2	6.3
A	7.3	7.1	6.5
S	6.6	6.8	6.6
O	5.1	5.6	5.7
N	3.4	3.8	4.0
D	2.4	2.7	2.9

Location: Dayton, OH Latitude: 39° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.8	3.1	3.2
F	3.6	3.8	3.8
M	4.7	4.8	4.6
A	5.3	5.1	4.6
M	6.0	5.5	4.9
J	6.4	5.8	5.0
J	6.4	5.9	5.2
A	6.1	5.9	5.4
S	5.5	5.6	5.4
O	4.5	4.9	5.0
N	3.0	3.3	3.5
D	2.5	2.8	3.0

Location: Denver, CO Latitude: 39° 40'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.8	5.5	5.9
F	5.8	6.3	6.4
M	6.4	6.6	6.4
A	6.6	6.4	5.8
M	6.8	6.3	5.5
J	7.3	6.6	5.7
J	7.2	6.6	5.8
A	7.1	6.9	6.3
S	6.6	6.8	6.5
O	5.7	6.2	6.3
N	4.5	5.2	5.5
D	4.1	4.8	5.2

INSOLATION

(kWh/m^2)

Location: Des Moines, IA Latitude: 41° 30'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.1	3.4	3.6
F	4.0	4.2	4.3
M	4.7	4.7	4.6
A	5.4	5.2	4.7
M	6.0	5.5	4.9
J	6.3	5.7	4.9
J	6.4	5.9	5.2
A	6.0	5.8	5.3
S	5.4	5.5	5.3
O	4.6	4.9	5.0
N	3.2	3.6	3.8
D	2.5	2.8	3.0

Location: Detroit, MI Latitude: 42° 10'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.4	2.6	2.7
F	3.3	3.5	3.5
M	4.4	4.4	4.2
A	4.9	4.7	4.3
M	5.8	5.3	4.7
J	6.2	5.6	4.9
J	6.3	5.8	5.1
A	5.9	5.6	5.1
S	5.2	5.2	5.0
O	4.2	4.5	4.5
N	2.4	2.7	2.8
D	2.0	2.3	2.4

Location: Dodge City, KA Latitude: 37° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.5	5.2	5.5
F	5.2	5.7	5.8
M	6.1	6.3	6.1
A	6.8	6.6	6.0
M	6.6	6.1	5.3
J	7.4	6.7	5.7
J	7.3	6.7	5.9
A	7.0	6.8	6.2
S	6.4	6.6	6.4
O	5.6	6.0	6.2
N	4.6	5.3	5.6
D	4.1	4.8	5.2

Location: Duluth, MN Latitude: 46° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.9	3.2	3.4
F	3.9	4.2	4.3
M	5.1	5.2	5.0
A	5.3	5.1	4.6
M	5.7	5.2	4.6
J	6.2	5.6	4.9
J	6.3	5.8	5.1
A	5.7	5.5	5.0
S	4.6	4.7	4.5
O	3.8	4.1	4.1
N	2.3	2.6	2.7
D	2.2	2.5	2.7

INSOLATION

(kWh/m^2)

Location: East Lansing, MI Latitude: 42° 40'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.0	2.2	2.2
F	3.3	3.5	3.5
M	4.3	4.3	4.1
A	4.3	4.1	3.7
M	5.4	5.0	4.4
J	5.8	5.2	4.5
J	5.8	5.3	4.7
A	5.3	5.1	4.7
S	4.6	4.7	4.5
O	3.6	3.8	3.9
N	2.0	2.2	2.3
D	1.7	1.9	2.0

Location: El Paso, TX Latitude: 31° 50'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	5.1	5.9	6.3
F	6.3	6.9	7.1
M	7.4	7.6	7.4
A	8.1	7.8	7.1
M	8.2	7.5	6.5
J	8.2	7.4	6.3
J	7.6	7.0	6.1
A	7.5	7.2	6.6
S	7.2	7.4	7.2
O	6.3	6.9	7.1
N	5.3	6.2	6.6
D	4.8	5.7	6.2

Location: Ely, NV Latitude: 39° 20'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.4	5.0	5.4
F	5.6	6.1	6.2
M	6.8	6.9	6.7
A	7.2	6.9	6.3
M	7.2	6.6	5.8
J	8.0	7.2	6.1
J	7.3	6.7	5.9
A	7.3	7.1	6.4
S	6.9	7.1	6.9
O	6.0	6.6	6.7
N	5.1	5.9	6.3
D	4.1	4.8	5.2

Location: Fairbanks, AK Latitude: 64° 50'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.0	2.3	2.4
F	3.2	3.5	3.6
M	6.2	6.4	6.2
A	6.5	6.3	5.7
M	6.1	5.6	4.8
J	6.1	5.5	4.7
J	5.3	4.8	4.1
A	5.0	4.8	4.3
S	3.2	3.3	3.1
O	2.4	2.5	2.6
N	1.5	1.7	1.8
D	0.7	0.8	0.9

INSOLATION

(kWh/m^2)

Location: Fargo, ND Latitude: 46° 50'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.7	3.1	3.2
F	4.0	4.3	4.4
M	4.9	5.0	4.8
A	5.5	5.3	4.8
M	6.0	5.5	4.8
J	5.9	5.3	4.6
J	6.3	5.8	5.1
A	5.8	5.6	5.1
S	4.8	4.9	4.7
O	4.0	4.3	4.3
N	2.4	2.7	2.8
D	2.6	3.0	3.2

Location: Fort Smith, AR Latitude: 35° 20'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.1	3.4	3.6
F	4.0	4.3	4.3
M	4.9	5.0	4.8
A	5.5	5.3	4.9
M	6.1	5.6	5.0
J	6.3	5.7	4.9
J	6.2	5.7	5.0
A	6.2	5.9	5.4
S	5.5	5.6	5.4
O	4.7	5.0	5.1
N	3.5	3.9	4.1
D	2.9	3.3	3.5

Location: Fort Wayne, IN Latitude: 41° 0'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.7	3.0	3.2
F	3.5	3.8	3.8
M	4.6	4.6	4.5
A	5.2	4.9	4.5
M	6.1	5.6	4.9
J	6.5	5.9	5.1
J	6.4	5.9	5.2
A	6.1	5.9	5.4
S	5.2	5.3	5.1
O	4.5	4.8	4.9
N	2.8	3.1	3.2
D	2.4	2.7	2.9

Location: Fort Worth, TX Latitude: 32° 50'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.8	4.3	4.5
F	4.6	5.0	5.0
M	5.7	5.8	5.6
A	3.5	3.4	3.1
M	6.4	5.9	5.2
J	7.2	6.6	5.6
J	6.9	6.4	5.6
A	6.9	6.7	6.1
S	6.3	6.4	6.2
O	5.3	5.8	5.9
N	4.3	4.9	5.2
D	3.7	4.2	4.6

INSOLATION

(kWh/m²)

Location: Fresno, CA Latitude: 36° 50'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.9	3.3	3.4
F	4.5	4.8	4.9
M	6.2	6.3	6.1
A	6.8	6.6	6.0
M	7.3	6.7	5.9
J	7.8	7.1	6.0
J	7.5	6.9	6.0
A	7.2	7.0	6.4
S	6.5	6.7	6.5
O	5.4	5.9	6.0
N	3.7	4.2	4.4
D	2.5	2.8	3.0

Location: Gainesville, FL Latitude: 29° 40'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.9	4.4	4.7
F	5.1	5.5	5.6
M	5.8	5.9	5.7
A	6.5	6.3	5.8
M	6.7	6.2	5.5
J	6.1	5.6	4.9
J	5.9	5.4	4.8
A	5.9	5.7	5.2
S	5.4	5.5	5.3
O	4.8	5.1	5.2
N	4.3	4.9	5.2
D	3.6	4.1	4.4

Location: Glasgow, MT Latitude: 48° 10'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.9	4.5	4.8
F	5.4	5.8	5.9
M	6.4	6.5	6.3
A	6.2	5.9	5.4
M	6.7	6.1	5.3
J	6.9	6.2	5.3
J	7.4	6.7	5.9
A	6.7	6.5	5.9
S	6.0	6.1	5.9
O	4.8	5.2	5.3
N	3.3	3.8	4.0
D	2.9	3.4	3.7

Location: Grand Junction, CO Latitude: 39° 10'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.2	4.8	5.1
F	5.4	5.9	6.0
M	6.2	6.4	6.2
A	6.8	6.6	6.0
M	7.0	6.4	5.6
J	7.9	7.2	6.1
J	7.6	7.0	6.1
A	7.0	6.7	6.2
S	6.7	6.9	6.7
O	5.7	6.2	6.4
N	4.5	5.1	5.5
D	4.0	4.7	5.1

INSOLATION

(kWh/m^2)

Location: Grand Lake, CO Latitude: 40° 20'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.9	4.5	4.7
F	5.4	5.8	5.9
M	6.2	6.3	6.1
A	6.6	6.4	5.8
M	6.4	5.9	5.2
J	7.1	6.4	5.5
J	6.8	6.2	5.4
A	6.0	5.8	5.3
S	6.4	6.5	6.3
O	5.6	6.1	6.2
N	4.1	4.6	4.9
D	3.4	4.0	4.3

Location: Great Falls, MT Latitude: 47° 30'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.1	3.6	3.8
F	4.5	4.8	4.9
M	5.9	6.1	5.9
A	5.7	5.5	5.0
M	6.2	5.7	5.0
J	6.7	6.0	5.2
J	7.4	6.8	5.9
A	6.6	6.4	5.8
S	5.8	5.9	5.7
O	4.5	4.9	5.0
N	3.1	3.5	3.7
D	2.5	2.9	3.1

Location: Green Bay, WI Latitude: 44° 30'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.7	3.0	3.2
F	3.7	3.9	3.9
M	4.7	4.8	4.6
A	5.0	4.8	4.4
M	5.8	5.3	4.7
J	6.1	5.5	4.8
J	6.1	5.6	4.9
A	5.6	5.4	4.9
S	4.8	4.9	4.7
O	3.7	4.0	4.0
N	2.4	2.7	2.8
D	2.1	2.4	2.6

Location: Greensboro, NC Latitude: 36° 0'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.3	3.7	3.9
F	4.1	4.3	4.4
M	4.8	4.9	4.7
A	5.9	5.6	5.2
M	6.1	5.6	4.9
J	6.3	5.7	4.9
J	6.1	5.6	4.9
A	5.6	5.4	4.9
S	5.2	5.3	5.1
O	4.6	4.9	5.0
N	3.8	4.2	4.5
D	3.0	3.4	3.6

INSOLATION

(kWh/m^2)

Location: Greenville-Spartanberg, NC   Latitude: 34° 50'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.5	3.9	4.1
F	3.9	4.2	4.2
M	5.2	5.3	5.2
A	6.3	6.1	5.6
M	6.3	5.8	5.1
J	6.3	5.7	4.9
J	6.3	5.8	5.1
A	6.0	5.8	5.3
S	5.3	5.4	5.2
O	5.0	5.4	5.5
N	3.8	4.3	4.5
D	3.2	3.7	3.9

Location: Griffin, GA   Latitude: 33° 10'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.6	4.1	4.3
F	4.4	4.7	4.7
M	5.2	5.3	5.1
A	6.3	6.1	5.6
M	6.6	6.1	5.4
J	6.5	5.9	5.1
J	6.3	5.8	5.1
A	6.2	5.9	5.4
S	5.4	5.5	5.3
O	5.0	5.4	5.5
N	4.2	4.8	5.0
D	3.1	3.6	3.8

Location: Hartford, CT   Latitude: 41° 60'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.9	3.2	3.4
F	3.8	4.0	4.0
M	4.8	4.8	4.7
A	4.9	4.7	4.3
M	5.6	5.1	4.5
J	6.0	5.4	4.7
J	6.0	5.5	4.9
A	5.6	5.3	4.9
S	4.7	4.8	4.6
O	3.9	4.2	4.2
N	2.7	3.0	3.2
D	3.7	4.3	4.7

Location: Hilo, HI   Latitude: 19° 40'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.4	3.8	3.9
F	4.5	4.8	4.9
M	5.4	5.5	5.3
A	5.1	4.9	4.5
M	5.1	4.8	4.3
J	6.5	6.0	5.2
J	6.2	5.8	5.1
A	5.7	5.5	5.0
S	5.2	5.3	5.2
O	4.0	4.3	4.3
N	3.6	3.9	4.1
D	3.2	3.6	3.8

INSOLATION

(kWh/m^2)

Location: Honolulu, HI — Latitude: 21° 20'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.6	5.2	5.5
F	5.3	5.7	5.8
M	6.3	6.4	6.2
A	6.5	6.3	5.8
M	7.1	6.6	5.7
J	7.0	6.4	5.5
J	7.1	6.5	5.7
A	7.1	6.9	6.3
S	6.7	6.9	6.7
O	6.1	6.6	6.8
N	5.2	6.0	6.4
D	4.7	5.5	5.9

Location: Houston, TX — Latitude: 29° 60'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.4	3.7	3.9
F	4.2	4.4	4.5
M	5.0	5.1	4.9
A	5.5	5.3	4.9
M	6.3	5.8	5.1
J	6.8	6.2	5.3
J	6.6	6.1	5.4
A	6.1	5.9	5.4
S	5.6	5.7	5.5
O	5.1	5.5	5.6
N	3.7	4.2	4.4
D	3.2	3.6	3.9

Location: Indianapolis, IN — Latitude: 39° 40'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.5	2.7	2.8
F	3.3	3.5	3.5
M	4.4	4.5	4.3
A	5.0	4.8	4.4
M	5.7	5.2	4.6
J	6.1	5.5	4.8
J	6.1	5.6	4.9
A	5.8	5.6	5.1
S	5.3	5.4	5.2
O	4.3	4.6	4.6
N	2.7	3.1	3.2
D	2.1	2.4	2.6

Location: Inyokern, CA — Latitude: 35° 40'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	5.3	6.2	6.6
F	6.7	7.3	7.5
M	8.2	8.4	8.2
A	8.8	8.5	7.8
M	9.1	8.3	7.2
J	9.3	8.4	7.1
J	8.8	8.1	7.0
A	8.9	8.6	7.8
S	8.4	8.7	8.4
O	7.0	7.7	8.0
N	5.9	6.8	7.3
D	5.1	6.1	6.6

INSOLATION

(kWh/m²)

Location: Ithaca, NY   Latitude: 42° 30'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.1	2.3	2.4
F	3.4	3.6	3.6
M	4.1	4.1	3.9
A	4.4	4.2	3.8
M	5.4	5.0	4.4
J	6.0	5.4	4.7
J	6.1	5.6	4.9
A	5.5	5.3	4.9
S	4.7	4.8	4.6
O	3.7	3.9	4.0
N	2.0	2.1	2.2
D	1.7	1.9	2.0

Location: Jackson, MS   Latitude: 32° 20'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.1	3.5	3.6
F	4.0	4.3	4.3
M	5.0	5.1	4.9
A	5.9	5.7	5.2
M	6.3	5.8	5.1
J	6.2	5.7	4.9
J	6.2	5.7	5.0
A	6.0	5.7	5.3
S	5.3	5.3	5.1
O	4.9	5.3	5.3
N	3.5	3.9	4.1
D	3.0	3.3	3.6

Location: Jacksonville, FL   Latitude: 30° 20'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.8	4.3	4.5
F	4.9	5.3	5.4
M	5.5	5.6	5.5
A	6.2	6.0	5.5
M	6.4	5.9	5.2
J	5.9	5.4	4.7
J	6.0	5.5	4.9
A	5.5	5.3	4.9
S	4.7	4.7	4.6
O	4.3	4.6	4.6
N	3.7	4.2	4.4
D	3.2	3.7	3.9

Location: Kansas City, MO   Latitude: 39° 20'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.2	3.5	3.7
F	4.0	4.3	4.4
M	4.8	4.9	4.7
A	5.6	5.4	4.9
M	6.0	5.5	4.9
J	6.6	6.0	5.2
J	6.5	6.0	5.3
A	6.3	6.1	5.6
S	5.5	5.6	5.4
O	4.7	5.1	5.2
N	3.5	4.0	4.2
D	2.9	3.3	3.5

INSOLATION

(kWh/m^2)

Location: Key West, FL   Latitude: 24° 30'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.3	4.9	5.1
F	5.3	5.8	5.9
M	6.1	6.3	6.1
A	6.8	6.5	6.0
M	6.7	6.2	5.4
J	6.2	5.7	4.9
J	6.1	5.7	5.0
A	5.8	5.6	5.1
S	5.3	5.4	5.2
O	4.8	5.2	5.3
N	4.2	4.7	5.0
D	3.8	4.3	4.6

Location: Lake Charles, LA   Latitude: 30° 10'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.4	3.8	4.0
F	4.3	4.5	4.6
M	5.1	5.2	5.0
A	5.8	5.6	5.1
M	6.3	5.8	5.1
J	6.5	6.0	5.1
J	5.9	5.4	4.8
A	5.9	5.6	5.2
S	5.5	5.6	5.4
O	5.3	5.8	5.9
N	4.1	4.6	4.8
D	3.3	3.7	3.9

Location: Lander, WY   Latitude: 42° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.8	5.6	6.0
F	5.9	6.4	6.5
M	6.9	7.1	6.9
A	7.3	7.0	6.4
M	6.9	6.4	5.6
J	7.5	6.8	5.8
J	7.3	6.8	5.9
A	7.1	6.8	6.2
S	6.4	6.6	6.4
O	5.8	6.3	6.5
N	4.4	5.1	5.5
D	4.1	4.8	5.2

Location: Lansing, MI   Latitude: 42° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.5	2.8	2.9
F	3.6	3.8	3.8
M	4.5	4.6	4.4
A	4.6	4.4	4.0
M	5.8	5.3	4.7
J	6.2	5.6	4.9
J	6.2	5.7	5.0
A	5.8	5.5	5.1
S	5.0	5.1	4.9
O	3.9	4.1	4.2
N	2.3	2.6	2.7
D	2.0	2.3	2.4

INSOLATION

(kWh/m²)

Location: Laramie, WY   Latitude: 41° 20'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.4	5.0	5.4
F	5.1	5.5	5.6
M	6.4	6.6	6.4
A	6.4	6.1	5.6
M	6.3	5.8	5.1
J	7.0	6.3	5.4
J	6.8	6.2	5.4
A	6.3	6.1	5.5
S	5.6	5.7	5.5
O	5.0	5.4	5.5
N	4.0	4.6	4.9
D	3.5	4.1	4.4

Location: Las Vegas, NV   Latitude: 36° 0'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.8	5.5	5.9
F	6.2	6.8	6.9
M	7.1	7.3	7.1
A	7.8	7.6	6.9
M	8.1	7.4	6.4
J	8.3	7.5	6.4
J	7.6	7.0	6.1
A	7.5	7.2	6.6
S	7.3	7.5	7.3
O	6.3	6.9	7.1
N	5.1	5.9	6.3
D	4.5	5.3	5.8

Location: Lemont, IL   Latitude: 41° 40'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.1	3.5	3.7
F	3.9	4.1	4.2
M	4.7	4.7	4.6
A	4.9	4.7	4.3
M	5.8	5.3	4.7
J	6.2	5.6	4.9
J	6.0	5.5	4.8
A	5.9	5.7	5.2
S	5.1	5.1	5.0
O	3.9	4.2	4.2
N	2.6	2.9	3.0
D	2.3	2.6	2.8

Location: Lexington, KY   Latitude: 38° 0'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.8	3.2	3.3
F	4.0	4.3	4.3
M	5.1	5.2	5.0
A	6.0	5.7	5.2
M	6.7	6.1	5.4
J	7.0	6.3	5.4
J	7.0	6.4	5.6
A	6.7	6.4	5.9
S	6.4	6.6	6.3
O	5.4	5.8	5.9
N	3.8	4.3	4.5
D	2.9	3.3	3.5

INSOLATION

(kWh/m^2)

Location: Lincoln, NE — Latitude: 40° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.5	3.9	4.2
F	4.2	4.5	4.5
M	5.0	5.1	4.9
A	5.4	5.2	4.7
M	5.8	5.3	4.7
J	6.1	5.5	4.8
J	6.1	5.6	4.9
A	6.1	5.9	5.4
S	5.4	5.5	5.3
O	5.0	5.4	5.5
N	3.5	3.9	4.1
D	3.1	3.6	3.9

Location: Little Rock, AR — Latitude: 34° 40'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.0	3.4	3.5
F	3.8	4.1	4.1
M	4.8	4.9	4.7
A	5.6	5.3	4.9
M	6.1	5.6	5.0
J	6.3	5.7	4.9
J	6.3	5.8	5.1
A	6.0	5.8	5.3
S	5.5	5.6	5.4
O	4.7	5.1	5.1
N	3.6	4.0	4.2
D	2.9	3.2	3.5

Location: Los Angeles, CA — Latitude: 33° 60'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.0	4.5	4.8
F	5.1	5.5	5.6
M	6.2	6.4	6.2
A	6.4	6.2	5.7
M	6.6	6.1	5.4
J	6.9	6.3	5.4
J	7.3	6.7	5.9
A	6.9	6.7	6.1
S	6.4	6.5	6.3
O	5.0	5.4	5.5
N	4.3	4.9	5.2
D	3.9	4.5	4.8

Location: Louisville, KY — Latitude: 38° 10'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.7	3.0	3.1
F	3.6	3.8	3.8
M	4.6	4.6	4.4
A	5.3	5.1	4.7
M	6.0	5.5	4.9
J	6.3	5.7	4.9
J	6.2	5.7	5.0
A	5.9	5.7	5.2
S	5.2	5.3	5.1
O	4.3	4.6	4.7
N	3.0	3.3	3.5
D	2.4	2.7	2.9

INSOLATION

(kWh/m²)

Location: Lynne, MA Latitude: 42° 30'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.1	2.3	2.3
F	3.5	3.7	3.7
M	4.4	4.4	4.2
A	5.0	4.8	4.4
M	5.3	4.9	4.3
J	6.0	5.4	4.7
J	6.1	5.6	4.9
A	5.0	4.8	4.4
S	4.4	4.5	4.3
O	3.4	3.6	3.7
N	2.1	2.3	2.4
D	1.7	1.9	2.0

Location: Macon, GA Latitude: 32° 40'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.7	4.2	4.4
F	4.5	4.8	4.8
M	5.2	5.3	5.1
A	6.2	6.0	5.5
M	6.5	6.0	5.3
J	6.4	5.8	5.0
J	6.2	5.7	5.0
A	6.1	5.8	5.3
S	5.4	5.4	5.2
O	5.0	5.3	5.4
N	3.8	4.3	4.5
D	3.2	3.7	3.9

Location: Madison, WI Latitude: 43° 10'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.0	3.4	3.5
F	3.8	4.1	4.1
M	5.0	5.0	4.9
A	5.0	4.8	4.4
M	5.6	5.1	4.5
J	6.2	5.6	4.9
J	6.3	5.8	5.1
A	5.8	5.5	5.0
S	5.3	5.4	5.2
O	4.2	4.5	4.6
N	2.6	2.9	3.0
D	2.6	3.0	3.2

Location: Manhattan, KA Latitude: 39° 10'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.4	3.8	4.0
F	4.2	4.5	4.6
M	4.8	4.9	4.7
A	5.5	5.3	4.8
M	6.1	5.6	4.9
J	6.2	5.6	4.9
J	6.0	5.5	4.8
A	6.3	6.1	5.6
S	5.3	5.4	5.2
O	4.3	4.6	4.6
N	3.8	4.3	4.6
D	2.7	3.0	3.2

INSOLATION

(kWh/m^2)

Location: Matanuska, AK Latitude: 61° 30'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	1.8	2.0	2.2
F	3.0	3.2	3.3
M	5.6	5.7	5.6
A	5.6	5.3	4.8
M	5.5	5.0	4.3
J	5.3	4.8	4.1
J	4.8	4.4	3.8
A	4.1	3.9	3.5
S	3.2	3.2	3.1
O	2.3	2.5	2.5
N	1.4	1.6	1.7
D	0.8	0.9	1.0

Location: Medford, OR Latitude: 42° 20'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.1	2.3	2.3
F	3.5	3.7	3.7
M	4.9	5.0	4.8
A	6.3	6.0	5.5
M	6.9	6.3	5.5
J	7.3	6.6	5.7
J	8.0	7.3	6.4
A	7.3	7.1	6.4
S	6.1	6.3	6.0
O	4.3	4.6	4.6
N	2.6	2.9	3.0
D	1.5	1.6	1.7

Location: Memphis, TN Latitude: 35° 0'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.9	3.3	3.4
F	3.9	4.2	4.2
M	4.8	4.9	4.7
A	5.8	5.5	5.1
M	6.4	5.9	5.2
J	6.6	6.0	5.2
J	6.6	6.1	5.3
A	6.4	6.1	5.6
S	5.6	5.7	5.5
O	5.0	5.4	5.5
N	3.6	4.0	4.2
D	2.9	3.2	3.4

Location: Miami, FL Latitude: 25° 50'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.7	5.3	5.6
F	5.5	5.9	6.1
M	6.2	6.4	6.2
A	6.4	6.2	5.7
M	6.4	5.9	5.2
J	6.0	5.5	4.8
J	6.1	5.7	5.0
A	5.9	5.7	5.2
S	5.4	5.5	5.3
O	4.9	5.2	5.3
N	4.6	5.2	5.5
D	4.3	4.9	5.3

INSOLATION

(kWh/m^2)

Location: Midland, TX Latitude: 31° 60'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.2	4.7	5.0
F	5.1	5.5	5.6
M	6.3	6.5	6.3
A	6.8	6.5	6.0
M	7.1	6.5	5.7
J	6.9	6.3	5.4
J	6.9	6.4	5.6
A	6.9	6.7	6.1
S	6.4	6.5	6.3
O	5.4	5.8	5.9
N	4.6	5.2	5.5
D	4.1	4.8	5.2

Location: Milwaukee, WI Latitude: 42° 60'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.8	3.1	3.3
F	3.5	3.8	3.8
M	4.5	4.6	4.4
A	5.1	4.9	4.5
M	5.9	5.4	4.8
J	6.3	5.7	5.0
J	6.4	5.9	5.2
A	5.9	5.6	5.1
S	5.2	5.3	5.1
O	4.0	4.3	4.4
N	2.7	3.1	3.2
D	2.2	2.5	2.6

Location: Minneapolis-St. Paul, MN Latitude: 44° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.9	3.3	3.4
F	3.9	4.2	4.3
M	4.6	4.7	4.5
A	5.1	4.9	4.5
M	5.7	5.2	4.6
J	6.0	5.4	4.7
J	6.2	5.7	5.0
A	5.6	5.4	4.9
S	4.9	5.0	4.8
O	4.1	4.4	4.4
N	2.5	2.8	2.9
D	2.2	2.5	2.6

Location: Mt. Weather, VA Latitude: 39° 0'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.0	3.3	3.4
F	4.4	4.8	4.8
M	4.7	4.8	4.6
A	5.2	5.0	4.5
M	5.9	5.4	4.8
J	5.9	5.3	4.6
J	5.8	5.3	4.7
A	5.1	4.9	4.5
S	4.8	4.9	4.7
O	4.1	4.4	4.4
N	3.2	3.6	3.8
D	2.9	3.3	3.5

INSOLATION

(kWh/m^2)

Location: Nashville, TN   Latitude: 36° 10'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.5	2.8	2.9
F	3.6	3.8	3.9
M	4.5	4.6	4.4
A	5.5	5.3	4.9
M	6.0	5.5	4.9
J	6.4	5.8	5.0
J	6.2	5.7	5.0
A	5.8	5.6	5.1
S	5.4	5.5	5.3
O	4.6	4.9	5.0
N	3.3	3.7	3.8
D	2.5	2.8	3.0

Location: Natick, MA   Latitude: 42° 20'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.8	3.1	3.3
F	3.9	4.2	4.2
M	4.8	4.8	4.7
A	5.0	4.8	4.4
M	5.8	5.3	4.7
J	4.5	4.1	3.6
J	5.8	5.3	4.7
A	5.4	5.2	4.8
S	4.7	4.8	4.6
O	4.0	4.3	4.3
N	2.4	2.7	2.8
D	2.5	2.9	3.0

Location: New Orleans, LA   Latitude: 29° 60'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.0	3.3	3.4
F	3.5	3.7	3.7
M	4.3	4.4	4.2
A	4.9	4.8	4.4
M	5.1	4.8	4.2
J	5.0	4.6	4.1
J	4.8	4.6	4.3
A	4.8	4.6	4.3
S	4.6	4.6	4.5
O	4.6	4.9	5.0
N	3.7	4.2	4.4
D		3.1	3.3

Location: Newport, RI   Latitude: 41° 30'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.8	3.1	3.2
F	3.8	4.0	4.1
M	4.8	4.9	4.7
A	5.0	4.8	4.4
M	5.7	5.2	4.6
J	6.0	5.4	4.7
J	5.9	5.4	4.8
A	5.3	5.1	4.7
S	5.0	5.0	4.8
O	4.1	4.4	4.4
N	2.9	3.2	3.4
D	2.5	2.9	3.1

INSOLATION

(kWh/m^2)

Location: New York, NY Latitude: 40° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.2	2.4	2.5
F	3.1	3.3	3.3
M	4.1	4.1	4.0
A	4.6	4.4	4.1
M	5.0	4.6	4.1
J	5.3	4.9	4.2
J	5.2	4.8	4.3
A	4.6	4.4	4.0
S	4.3	4.3	4.1
O	3.5	3.7	3.7
N	2.2	2.5	2.6
D	1.9	2.1	2.2

Location: North Omaha, NE Latitude: 41° 20'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.0	4.5	4.8
F	4.7	5.1	5.2
M	5.2	5.3	5.1
A	5.9	5.7	5.2
M	6.0	5.5	4.9
J	6.3	5.7	4.9
J	6.4	5.9	5.2
A	6.3	6.1	5.5
S	5.3	5.4	5.2
O	4.5	4.8	4.9
N	3.4	3.8	4.0
D	3.1	3.6	3.9

Location: Norfolk, VA Latitude: 36° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.4	3.8	4.0
F	4.1	4.4	4.5
M	5.1	5.2	5.0
A	6.0	5.8	5.3
M	6.2	5.8	5.0
J	6.4	5.8	5.0
J	6.2	5.7	5.0
A	5.7	5.5	5.0
S	5.1	5.1	5.0
O	4.4	4.7	4.7
N	3.4	3.8	4.0
D	3.0	3.4	3.6

Location: Oak Ridge, TN Latitude: 36° 0'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.6	2.9	3.0
F	3.5	3.7	3.8
M	4.4	4.5	4.3
A	5.5	5.3	4.9
M	5.9	5.4	4.8
J	6.1	5.5	4.8
J	5.9	5.4	4.8
A	5.6	5.4	4.9
S	5.3	5.4	5.2
O	4.5	4.8	4.9
N	3.1	3.5	3.6
D	2.5	2.8	3.0

INSOLATION

(kWh/m^2)

Location: Oklahoma City, OK Latitude: 35° 20'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.1	4.7	5.0
F	4.8	5.2	5.3
M	5.6	5.7	5.5
A	6.2	6.0	5.5
M	6.2	5.7	5.0
J	7.0	6.4	5.5
J	6.8	6.3	5.5
A	7.0	6.8	6.2
S	6.1	6.3	6.1
O	5.4	5.8	5.9
N	4.4	5.0	5.3
D	3.9	4.5	4.9

Location: Page, AZ Latitude: 36° 40'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	5.3	6.1	6.6
F	6.2	6.7	6.9
M	7.6	7.8	7.6
A	7.8	7.6	6.9
M	8.1	7.4	6.5
J	7.9	7.2	6.1
J	7.7	7.1	6.2
A	7.1	6.9	6.3
S	6.7	6.9	6.7
O	5.9	6.4	6.6
N	5.0	5.7	6.1
D	4.1	4.8	5.3

Location: Parkersburg, WV Latitude: 39° 20'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.3	2.6	2.7
F	3.2	3.3	3.3
M	4.2	4.3	4.1
A	4.8	4.6	4.2
M	5.7	5.2	4.6
J	6.1	5.5	4.8
J	6.0	5.5	4.8
A	5.8	5.6	5.1
S	5.1	5.2	5.0
O	4.1	4.4	4.4
N	2.6	2.9	3.0
D	2.2	2.4	2.6

Location: Pasadena, CA Latitude: 34° 10'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.9	4.4	4.7
F	5.0	5.4	5.5
M	6.0	6.1	5.9
A	6.3	6.1	5.6
M	6.5	6.0	5.3
J	6.5	5.9	5.1
J	7.2	6.6	5.8
A	7.1	6.9	6.3
S	6.1	6.2	6.0
O	5.0	5.4	5.5
N	4.0	4.5	4.8
D	3.7	4.3	4.6

INSOLATION

(kWh/m^2)

Location: Pensacola, FL Latitude: 30° 30'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.6	4.0	4.2
F	4.5	4.8	4.9
M	5.2	5.3	5.1
A	6.2	6.0	5.5
M	6.4	5.9	5.2
J	6.3	5.8	5.0
J	6.1	5.6	5.0
A	6.0	5.8	5.3
S	5.3	5.4	5.2
O	5.2	5.6	5.7
N	3.8	4.3	4.5
D	3.2	3.6	3.8

Location: Peoria, IL Latitude: 40° 40'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.9	3.2	3.4
F	3.6	3.9	3.9
M	4.6	4.7	4.5
A	5.4	5.2	4.7
M	5.9	5.4	4.8
J	6.4	5.8	5.0
J	6.4	5.9	5.2
A	6.0	5.8	5.3
S	5.4	5.5	5.3
O	4.5	4.8	4.9
N	3.0	3.4	3.5
D	2.4	2.7	2.9

Location: Phoenix, AZ Latitude: 33° 30'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.7	5.4	5.7
F	6.2	6.7	6.9
M	7.2	7.4	7.2
A	8.0	7.7	7.0
M	8.3	7.6	6.6
J	8.2	7.4	6.3
J	7.4	6.8	5.9
A	7.2	7.0	6.4
S	7.2	7.4	7.2
O	6.3	6.9	7.1
N	5.1	5.9	6.3
D	4.5	5.2	5.7

Location: Philadelphia, PA Latitude: 39° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.1	3.4	3.6
F	3.8	4.1	4.1
M	4.9	5.0	4.8
A	5.4	5.2	4.7
M	5.7	5.2	4.6
J	6.2	5.6	4.9
J	6.1	5.6	4.9
A	5.6	5.4	4.9
S	5.0	5.1	4.9
O	4.2	4.6	4.6
N	3.0	3.4	3.6
D	2.6	3.0	3.2

INSOLATION

(kWh/m^2)

Location: Pittsburgh, PA Latitude: 40° 30'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.7	3.0	3.2
F	3.4	3.6	3.6
M	4.6	4.7	4.5
A	5.1	4.9	4.4
M	5.7	5.2	4.6
J	6.3	5.7	4.9
J	6.2	5.7	5.0
A	5.8	5.6	5.1
S	5.3	5.4	5.2
O	4.4	4.7	4.8
N	3.0	3.4	3.5
D	2.5	2.8	3.0

Location: Pocatello, ID Latitude: 42° 50'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.2	3.6	3.7
F	4.3	4.6	4.7
M	5.5	5.6	5.4
A	6.8	6.6	6.0
M	6.8	6.3	5.5
J	7.3	6.6	5.7
J	7.7	7.1	6.1
A	7.2	7.0	6.3
S	6.5	6.7	6.5
O	5.3	5.7	5.9
N	3.7	4.2	4.5
D	3.0	3.5	3.8

Location: Port Arthur, TX Latitude: 29° 60'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.2	3.6	3.7
F	4.1	4.3	4.4
M	4.9	5.0	4.8
A	5.3	5.1	4.7
M	6.2	5.8	5.1
J	6.4	5.9	5.1
J	6.0	5.5	4.9
A	5.6	5.5	5.0
S	5.3	5.4	5.2
O	4.9	5.3	5.4
N	3.4	3.8	4.0
D	3.0	3.3	3.6

Location: Portland, ME Latitude: 43° 40'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.1	3.5	3.7
F	4.2	4.5	4.5
M	5.5	5.6	5.4
A	5.2	5.0	4.6
M	6.0	5.5	4.8
J	6.1	5.5	4.8
J	6.3	5.8	5.1
A	5.9	5.6	5.1
S	5.1	5.2	5.0
O	4.3	4.6	4.7
N	2.7	3.0	3.2
D	2.7	3.1	3.3

INSOLATION

(kWh/m^2)

Location: Portland, OR Latitude: 45° 40'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	1.8	1.9	2.0
F	2.7	2.8	2.8
M	3.6	3.6	3.4
A	4.6	4.4	4.0
M	5.0	4.6	4.0
J	5.3	4.8	4.2
J	6.3	5.8	5.1
A	5.4	5.2	4.7
S	4.7	4.7	4.5
O	3.1	3.2	3.3
N	2.0	2.2	2.3
D	1.5	1.7	1.8

Location: Prosser, WA Latitude: 46° 10'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.4	2.7	2.8
F	4.2	4.5	4.5
M	5.6	5.8	5.6
A	7.0	6.7	6.1
M	7.4	6.8	5.9
J	7.7	6.9	5.9
J	8.1	7.5	6.5
A	7.7	7.4	6.7
S	6.7	6.9	6.7
O	4.7	5.1	5.1
N	2.5	2.8	3.0
D	2.0	2.3	2.5

Location: Pueblo, CO Latitude: 38° 20'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	5.0	5.7	6.1
F	5.8	6.3	6.5
M	6.5	6.6	6.4
A	7.0	6.7	6.1
M	7.0	6.4	5.6
J	7.5	6.8	5.8
J	7.3	6.7	5.9
A	7.2	7.0	6.4
S	6.6	6.8	6.6
O	5.9	6.5	6.6
N	5.0	5.8	6.2
D	4.4	5.2	5.6

Location: Pullman, WA Latitude: 46° 40'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.6	2.9	3.0
F	3.3	3.5	3.6
M	4.7	4.7	4.5
A	6.1	5.9	5.3
M	6.5	5.9	5.2
J	7.7	6.9	5.9
J	8.2	7.5	6.5
A	6.9	6.6	6.0
S	6.1	6.3	6.1
O	4.3	4.6	4.7
N	2.8	3.2	3.4
D	1.9	2.2	2.3

INSOLATION

(kWh/m^2)

Location: Put-In-Bay, OH   Latitude: 41° 40'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.0	2.2	2.3
F	3.2	3.4	3.4
M	4.2	4.2	4.0
A	4.7	4.5	4.1
M	5.8	5.3	4.7
J	6.1	5.5	4.8
J	6.4	5.9	5.2
A	6.2	6.0	5.5
S	5.3	5.4	5.2
O	4.5	4.8	4.9
N	2.6	2.9	3.0
D	1.9	2.1	2.2

Location: Raleigh, NC   Latitude: 35° 50'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.9	4.4	4.6
F	4.6	5.0	5.1
M	5.5	5.6	5.5
A	5.9	5.7	5.2
M	5.8	5.4	4.7
J	6.4	5.8	5.0
J	6.1	5.6	4.9
A	5.7	5.5	5.0
S	4.9	4.9	4.8
O	4.3	4.6	4.7
N	3.6	4.0	4.3
D	3.2	3.7	4.0

Location: Raleigh-Durham, NC   Latitude: 35° 50'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.5	3.9	4.1
F	4.3	4.6	4.6
M	5.1	5.2	5.0
A	6.0	5.8	5.3
M	6.0	5.6	4.9
J	6.0	5.4	4.7
J	6.2	5.7	5.0
A	5.7	5.5	5.0
S	5.0	5.1	4.9
O	4.4	4.7	4.8
N	3.6	4.0	4.3
D	3.1	3.5	3.8

Location: Rapid City, SD   Latitude: 44° 10'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.0	4.6	4.8
F	5.2	5.7	5.8
M	6.2	6.4	6.2
A	6.3	6.1	5.6
M	6.3	5.8	5.1
J	6.7	6.0	5.2
J	6.8	6.2	5.4
A	6.6	6.4	5.8
S	6.0	6.1	5.9
O	5.1	5.6	5.7
N	4.0	4.5	4.8
D	3.3	3.9	4.2

INSOLATION

(kWh/m²)

Location: Reno, NV Latitude: 39° 30'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.3	4.9	5.2
F	5.4	5.8	6.0
M	6.5	6.7	6.5
A	7.6	7.3	6.7
M	7.8	7.2	6.2
J	8.0	7.2	6.1
J	8.0	7.3	6.4
A	7.8	7.5	6.9
S	7.1	7.4	7.1
O	6.1	6.7	6.9
N	4.8	5.5	5.9
D	3.8	4.5	4.8

Location: Richland, WA Latitude: 46° 20'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	1.6	1.7	1.8
F	3.7	3.9	4.0
M	5.2	5.3	5.1
A	6.2	6.0	5.4
M	6.1	5.6	4.9
J	7.2	6.5	5.6
J	6.6	6.0	5.3
A	7.5	7.3	6.6
S	5.5	5.6	5.4
O	3.7	4.0	4.0
N	2.2	2.5	2.6
D	2.0	2.3	2.4

Location: Richmond, VA Latitude: 37° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.1	3.5	3.7
F	3.9	4.2	4.2
M	5.0	5.1	4.9
A	5.7	5.5	5.1
M	6.0	5.6	4.9
J	6.3	5.7	5.0
J	6.3	5.8	5.1
A	5.7	5.5	5.0
S	5.0	5.1	4.9
O	4.3	4.6	4.7
N	3.2	3.6	3.8
D	2.8	3.2	3.4

Location: Riverside, CA Latitude: 33° 60'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.3	4.9	5.3
F	5.5	5.9	6.0
M	6.5	6.7	6.5
A	6.6	6.4	5.9
M	7.2	6.6	5.8
J	7.6	6.9	5.9
J	7.6	7.0	6.1
A	7.3	7.1	6.5
S	6.8	7.0	6.7
O	5.7	6.2	6.3
N	4.8	5.5	5.9
D	4.3	5.0	5.4

INSOLATION

(kWh/m²)

Location: Rochester, NY Latitude: 43° 10'

MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
	TILT ANGLE		
J	2.5	2.8	3.0
F	3.4	3.6	3.6
M	4.4	4.5	4.3
A	5.1	4.9	4.5
M	6.0	5.5	4.8
J	6.4	5.8	5.0
J	6.5	6.0	5.3
A	6.0	5.7	5.2
S	5.0	5.1	4.9
O	3.8	4.1	4.2
N	2.5	2.7	2.9
D	2.1	2.4	2.5

Location: Sacramento, CA Latitude: 38° 30'

MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
	TILT ANGLE		
J	2.7	2.9	3.1
F	4.2	4.5	4.5
M	5.7	5.8	5.6
A	6.7	6.5	5.9
M	7.9	7.2	6.3
J	7.6	6.9	5.9
J	7.8	7.1	6.2
A	7.0	6.8	6.2
S	6.4	6.5	6.3
O	5.4	5.9	6.0
N	3.6	4.0	4.3
D	2.5	2.8	3.0

Location: St. Cloud, MN Latitude: 45° 30'

MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
	TILT ANGLE		
J	3.7	4.3	4.5
F	4.8	5.1	5.2
M	5.8	5.9	5.7
A	5.6	5.3	4.8
M	5.9	5.4	4.7
J	6.1	5.5	4.8
J	6.3	5.8	5.1
A	6.1	5.8	5.3
S	5.0	5.1	4.9
O	3.8	4.1	4.2
N	2.7	3.0	3.2
D	2.6	3.0	3.2

Location: St. Louis, MO Latitude: 38° 40'

MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
	TILT ANGLE		
J	3.0	3.3	3.5
F	3.9	4.1	4.2
M	4.9	4.9	4.7
A	5.4	5.2	4.7
M	6.1	5.6	5.0
J	6.4	5.8	5.0
J	6.4	5.9	5.2
A	5.9	5.7	5.2
S	5.4	5.5	5.3
O	4.5	4.8	4.9
N	3.3	3.7	3.9
D	2.5	2.9	3.1

INSOLATION

(kWh/m²)

Location: Salt Lake City, UT   Latitude: 40° 50'

	TILT ANGLE		
MONTH	LATITUDE −15°	LATITUDE	LATITUDE +15°
J	2.9	3.2	3.4
F	4.2	4.5	4.5
M	5.1	5.2	5.0
A	6.2	5.9	5.4
M	6.7	6.2	5.4
J	7.0	6.3	5.4
J	7.0	6.4	5.6
A	6.7	6.4	5.9
S	5.9	6.1	5.9
O	4.8	5.2	5.2
N	3.4	3.8	4.0
D	2.6	2.9	3.1

Location: San Antonio, TX   Latitude: 29° 30'

	TILT ANGLE		
MONTH	LATITUDE −15°	LATITUDE	LATITUDE +15°
J	4.0	4.4	4.7
F	4.8	5.2	5.3
M	5.5	5.6	5.4
A	5.4	5.2	4.8
M	6.2	5.7	5.1
J	6.8	6.2	5.3
J	7.0	6.5	5.7
A	6.8	6.6	6.0
S	6.0	6.1	5.9
O	5.1	5.6	5.7
N	3.9	4.4	4.7
D	3.5	4.0	4.3

Location: San Diego, CA   Latitude: 32° 40'

	TILT ANGLE		
MONTH	LATITUDE −15°	LATITUDE	LATITUDE +15°
J	4.1	4.6	4.9
F	5.0	5.4	5.5
M	5.7	5.8	5.6
A	5.7	5.5	5.0
M	5.7	5.3	4.6
J	5.7	5.2	4.5
J	6.2	5.7	5.0
A	5.8	5.6	5.2
S	5.6	5.7	5.5
O	4.9	5.2	5.3
N	4.0	4.6	4.8
D	3.7	4.3	4.9

Location: San Francisco, CA   Latitude: 37° 50'

	TILT ANGLE		
MONTH	LATITUDE −15°	LATITUDE	LATITUDE +15°
J	3.2	3.6	3.8
F	4.4	4.7	4.8
M	5.7	5.8	5.6
A	6.4	6.2	5.6
M	6.7	6.2	5.4
J	6.7	6.1	5.3
J	6.1	5.6	4.9
A	5.7	5.5	5.0
S	5.5	5.6	5.4
O	4.8	5.2	5.3
N	3.6	4.1	4.3
D	2.9	3.3	3.5

INSOLATION

(kWh/m^2)

Location: Santa Maria, CA Latitude: 34° 50'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.2	4.8	5.1
F	5.3	5.8	5.9
M	6.7	6.9	6.7
A	7.0	6.7	6.1
M	7.3	6.7	5.9
J	7.8	7.1	6.0
J	7.7	7.1	6.2
A	7.2	7.0	6.4
S	6.7	6.8	6.6
O	5.9	6.5	6.6
N	4.8	5.5	5.9
D	4.1	4.7	5.1

Location: Savannah, GA Latitude: 32° 10'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.7	4.1	4.3
F	4.5	4.8	4.8
M	5.3	5.4	5.2
A	6.3	6.1	5.6
M	6.4	5.9	5.2
J	6.2	5.7	4.9
J	6.1	5.6	4.9
A	5.8	5.6	5.2
S	5.0	5.0	4.8
O	4.6	4.9	5.0
N	3.7	4.2	4.4
D	3.2	3.6	3.9

Location: Sault St. Marie, MI Latitude: 46° 30'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.8	3.2	3.3
F	4.3	4.7	4.7
M	5.7	5.9	5.7
A	5.5	5.3	4.8
M	6.2	5.7	5.0
J	6.2	5.6	4.8
J	6.6	6.0	5.3
A	5.8	5.6	5.1
S	4.4	4.5	4.3
O	3.5	3.7	3.7
N	1.8	2.0	2.0
D	2.0	2.2	2.4

Location: Schenectady, NY Latitude: 42° 50'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.3	2.6	2.7
F	3.3	3.5	3.5
M	3.9	4.0	3.8
A	4.3	4.1	3.7
M	4.8	4.4	3.9
J	5.0	4.6	4.0
J	5.0	4.6	4.1
A	4.8	4.6	4.2
S	3.9	3.9	3.8
O	3.2	3.4	3.5
N	2.0	2.2	2.3
D	1.8	2.0	2.1

INSOLATION

(kWh/m²)

Location: Seattle, WA   Latitude: 47° 30'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	1.5	1.6	1.7
F	2.3	2.4	2.4
M	4.1	4.2	4.0
A	5.3	5.1	4.6
M	5.9	5.4	4.7
J	5.9	5.3	4.6
J	6.4	5.9	5.2
A	5.8	5.6	5.1
S	4.5	4.6	4.4
O	3.0	3.2	3.2
N	1.9	2.1	2.2
D	1.4	1.6	1.7

Location: Shreveport, LA   Latitude: 32° 20'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.4	3.7	3.9
F	4.0	4.3	4.3
M	5.0	5.1	4.9
A	5.7	5.5	5.0
M	6.3	5.8	5.1
J	6.1	5.6	4.9
J	6.3	5.8	5.1
A	6.1	5.8	5.3
S	5.2	5.2	5.0
O	4.6	4.9	5.0
N	3.4	3.8	4.0
D	2.9	3.3	3.5

Location: Silver Hill, MD   Latitude: 38° 50'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.1	3.5	3.6
F	3.8	4.0	4.1
M	4.7	4.8	4.6
A	5.5	5.3	4.8
M	5.9	5.4	4.8
J	6.2	5.6	4.9
J	5.9	5.4	4.8
A	5.5	5.3	4.8
S	5.1	5.2	5.0
O	4.2	4.5	4.5
N	3.2	3.5	3.7
D	2.7	3.1	3.3

Location: Spokane, WA   Latitude: 47° 40'

MONTH	TILT ANGLE LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.6	2.9	3.1
F	4.2	4.5	4.6
M	5.1	5.2	5.0
A	6.3	6.1	5.5
M	6.6	6.0	5.3
J	6.8	6.1	5.3
J	7.7	7.1	6.1
A	7.0	6.7	6.1
S	5.9	6.0	5.8
O	3.3	3.5	3.6
N	2.5	2.8	3.0
D	1.5	1.7	1.8

INSOLATION

(kWh/m^2)

Location: State College, PA   Latitude: 40° 50'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.3	2.6	2.7
F	3.2	3.4	3.4
M	4.2	4.2	4.1
A	4.7	4.5	4.1
M	5.5	5.0	4.4
J	6.1	5.5	4.8
J	6.0	5.5	4.9
A	5.5	5.2	4.8
S	4.7	4.7	4.5
O	4.0	4.3	4.4
N	2.5	2.7	2.9
D	2.0	2.3	2.4

Location: Stillwater, OK   Latitude: 36° 10'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.4	3.8	4.0
F	4.4	4.7	4.7
M	5.3	5.4	5.2
A	5.6	5.4	5.0
M	5.8	5.3	4.7
J	6.6	6.0	5.2
J	6.7	6.2	5.4
A	6.5	6.2	5.7
S	5.8	5.9	5.7
O	4.9	5.3	5.4
N	4.0	4.5	4.8
D	3.3	3.8	4.1

Location: Summit, MT   Latitude: 48° 20'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.9	3.2	3.4
F	3.1	3.3	3.3
M	4.2	4.3	4.1
A	5.6	5.4	4.9
M	5.4	5.0	4.4
J	5.5	5.0	4.3
J	6.4	5.9	5.2
A	6.4	6.1	5.6
S	5.0	5.1	4.9
O	3.6	3.9	3.9
N	1.9	2.1	2.2
D	1.6	1.8	1.9

Location: Syracuse, NY   Latitude: 43° 10'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.4	2.7	2.8
F	3.2	3.4	3.4
M	4.2	4.3	4.1
A	4.8	4.6	4.2
M	5.7	5.2	4.6
J	6.2	5.6	4.9
J	6.3	5.8	5.1
A	5.7	5.4	4.9
S	4.8	4.9	4.7
O	3.7	3.9	3.9
N	2.0	2.2	2.3
D	1.9	2.1	2.2

INSOLATION

(kWh/m²)

Location: Tallahassee, FL Latitude: 30° 30'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.5	3.9	4.1
F	4.3	4.6	4.7
M	5.5	5.6	5.5
A	5.8	5.6	5.1
M	6.3	5.8	5.1
J	5.4	4.9	4.3
J	6.2	5.7	5.0
A	6.3	6.1	5.5
S	5.2	5.3	5.1
O	4.6	4.9	5.0
N	5.1	5.9	6.3
D	4.7	5.4	5.9

Location: Tampa, FL Latitude: 27° 60'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.6	5.2	5.5
F	5.3	5.8	5.9
M	6.1	6.2	6.0
A	6.6	6.3	5.8
M	6.8	6.3	5.6
J	6.4	5.9	5.1
J	6.1	5.6	5.0
A	5.8	5.6	5.1
S	5.4	5.5	5.3
O	5.2	5.6	5.7
N	4.8	5.5	5.8
D	4.2	4.8	5.2

Location: Trenton, NJ Latitude: 40° 10'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.1	3.4	3.6
F	3.9	4.2	4.2
M	4.9	5.0	4.8
A	5.4	5.2	4.7
M	5.7	5.2	4.6
J	6.1	5.5	4.8
J	6.1	5.6	4.9
A	5.6	5.4	4.9
S	5.1	5.2	5.0
O	4.3	4.7	4.7
N	3.2	3.6	3.8
D	2.8	3.1	3.4

Location: Tucson, AZ Latitude: 32° 10'

TILT ANGLE			
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.9	5.5	5.9
F	5.9	6.4	6.6
M	7.4	7.6	7.4
A	8.2	7.9	7.2
M	8.5	7.8	6.8
J	7.9	7.1	6.1
J	7.0	6.5	5.7
A	6.9	6.7	6.1
S	7.3	7.6	7.3
O	6.1	6.7	6.9
N	5.3	6.0	6.5
D	4.6	5.4	5.8

INSOLATION

(kWh/m^2)

Location: Tulsa, OK   Latitude: 36° 10'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.4	3.8	4.0
F	4.2	4.4	4.5
M	5.1	5.2	5.0
A	5.4	5.2	4.8
M	6.0	5.5	4.9
J	6.5	5.9	5.1
J	6.4	5.9	5.2
A	6.3	6.0	5.5
S	5.6	5.7	5.5
O	4.7	5.0	5.1
N	3.6	4.0	4.3
D	3.2	3.6	3.9

Location: Twin Falls, ID   Latitude: 40° 30'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.9	3.2	3.4
F	3.9	4.2	4.2
M	5.1	5.2	5.0
A	5.9	5.7	5.2
M	6.4	5.9	5.2
J	6.6	6.0	5.2
J	6.9	6.3	5.5
A	6.6	6.3	5.8
S	5.7	5.8	5.6
O	4.2	4.5	4.6
N	2.9	3.2	3.4
D	2.3	2.5	2.7

Location: Washington, DC   Latitude: 38° 50'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	2.6	2.9	3.1
F	3.5	3.7	3.8
M	4.4	4.5	4.3
A	5.1	4.9	4.5
M	5.1	4.7	4.2
J	6.2	5.6	4.9
J	6.0	5.5	4.9
A	5.5	5.3	4.8
S	4.7	4.8	4.6
O	4.0	4.3	4.3
N	3.3	3.7	3.9
D	2.4	2.7	2.9

Location: Wichita, KS   Latitude: 37° 40'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	3.8	4.3	4.5
F	4.5	4.8	4.9
M	5.3	5.4	5.2
A	6.0	5.7	5.2
M	6.3	5.8	5.1
J	6.7	6.1	5.3
J	6.6	6.1	5.4
A	6.5	6.2	5.7
S	5.8	5.9	5.7
O	5.0	5.4	5.5
N	3.9	4.5	4.7
D	3.3	3.8	4.1

INSOLATION

(kWh/m^2)

Location: Yuma, AZ   Latitude: 32° 40'

	TILT ANGLE		
MONTH	LATITUDE -15°	LATITUDE	LATITUDE +15°
J	4.7	5.4	5.8
F	6.0	6.5	6.7
M	7.0	7.2	7.0
A	7.8	7.6	6.9
M	8.0	7.4	6.4
J	7.9	7.1	6.1
J	7.4	6.8	5.9
A	6.9	6.7	6.1
S	6.7	6.9	6.7
O	6.1	6.7	6.8
N	4.9	5.6	6.0
D	4.2	4.8	5.2

Appendix E

STORAGE BATTERY SPECIFICATION SHEET

AD-A120 814   FLAT PLATE PHOTOVOLTAIC POWER SYSTEMS: DESCRIPTION DESIGN AND COST(U) NAVAL WEAPONS CENTER CHINA LAKE CA M R HALL ET AL. JUL 82 NWC-TP-6381   2/2

UNCLASSIFIED   F/G 10/2   NL

END

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Volts	Cut-off Voltage	Amp. Hr. Capacity	Current Rate Amps	Specific Gravity Chgd.	Specific Gravity Disch.	Plates Per Cell
6	1.90	200	0.5	1.300	1.120	5
	1.75	220	0.5	1.300	1.110	

Plate Dimensions	Width	Height	Thickness Positive	Thickness Negative	Thickness End Neg.
Plate Dimensions in Inches	5⅝	5¼	⅝	⅝	5/16
Plate Dimensions in Centimeters	14.3	13.3	1.6	1.6	0.8

Part No.	Description	Overall Battery Dimensions in Inches			Net Weight in Pounds	Terminal Hole Diameter in Inches
		Length	Width	Height		
4118	Standard	16⅛	7 1/16	9½	76	9/32
5780	With spill-proof vents	16⅛	7 1/16	9½	76	9/32
9195	In square steel cans	16 15/16	7⅝	10½	80	9/32
4500	Epoxy sealed	16⅛	7 1/16	9½	76	9/32

Part No.	Description	Overall Battery Dimensions in Centimeters			Net Weight in Kilograms	Terminal Hole Diameter in Centimeters
		Length	Width	Height		
4118	Standard	40.9	17.9	24.1	34.5	0.7
5780	With spill-proof vents	40.9	17.9	24.1	34.5	0.7
9195	In square steel cans	43	19.4	26.7	36.3	0.7
4500	Epoxy sealed	40.9	17.9	24.1	34.5	0.7

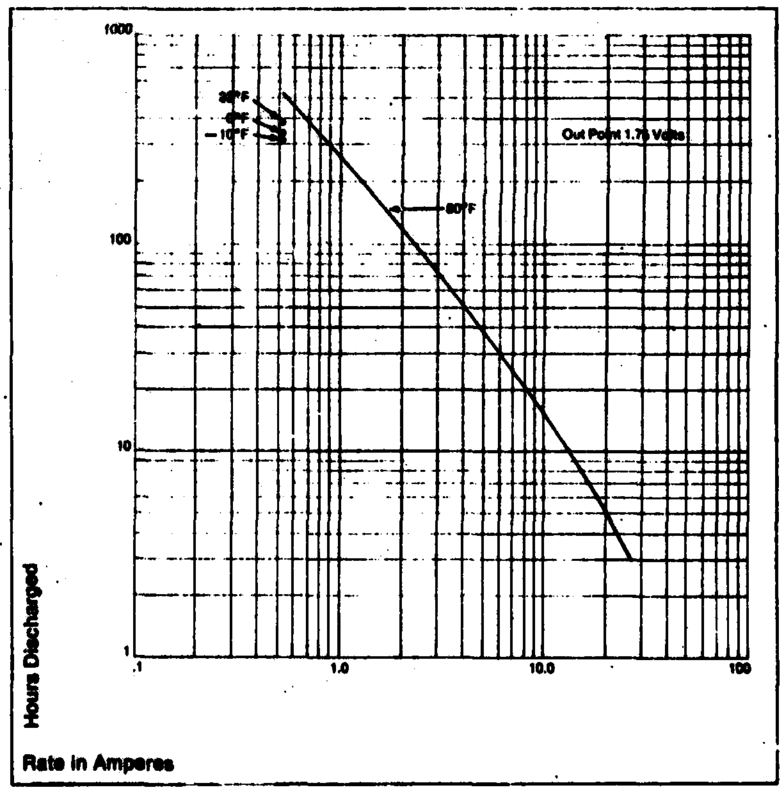
Recommended Charging Voltages

For minimum water loss 2.30 volts/cell
For maximum recharge 2.40 volts/cell

Electrolyte level should be ⅞" (2.2 cm) above the battery plates.

Use potable odorless water for filling to this level.

Design Curve



Appendix F

INFLATION-DISCOUNT FACTORS[2]

In these tables, the single-amount factors are to be applied to one-time costs occurring in isolated years. Cumulative-uniform-series factors are to be applied to identical annually recurrent cash flows. The table numbers correspond to the Differential Inflation Rate.

[2] Naval Facilities Engineering Command. *Economic Analysis Handbook*. Alexandria, Va., NAVFAC, June 1975. Pp. E-1—E-17. (NAVFAC P-442, publication UNCLASSIFIED.)

Table -5

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = -5%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.933	0.933
2	0.812	1.745
3	0.706	2.450
4	0.614	3.064
5	0.534	3.598
6	0.464	4.062
7	0.403	4.465
8	0.351	4.816
9	0.305	5.121
10	0.265	5.386
11	0.231	5.617
12	0.201	5.818
13	0.174	5.992
14	0.152	6.144
15	0.132	6.276
16	0.115	6.390
17	0.100	6.490
18	0.087	6.577
19	0.075	6.652
20	0.066	6.718
21	0.057	6.775
22	0.050	6.824
23	0.043	6.868
24	0.037	6.905
25	0.033	6.938
26	0.028	6.966
27	0.025	6.991
28	0.021	7.012
29	0.019	7.031
30	0.016	7.047

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 5% slower than general price levels.

Table -4

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = -4%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.937	0.937
2	0.822	1.759
3	0.721	2.481
4	0.633	3.113
5	0.555	3.668
6	0.487	4.155
7	0.427	4.582
8	0.374	4.956
9	0.329	5.285
10	0.288	5.573
11	0.253	5.826
12	0.222	6.048
13	0.195	6.242
14	0.171	6.413
15	0.150	6.563
16	0.131	6.694
17	0.115	6.809
18	0.101	6.910
19	0.089	6.999
20	0.078	7.077
21	0.068	7.145
22	0.060	7.205
23	0.052	7.257
24	0.046	7.303
25	0.040	7.344
26	0.035	7.379
27	0.031	7.410
28	0.027	7.437
29	0.024	7.461
30	0.021	7.482

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 4% slower than general price levels.

Table -3

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = -3%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.941	0.941
2	0.833	1.774
3	0.737	2.511
4	0.652	3.164
5	0.577	3.741
6	0.511	4.252
7	0.452	4.704
8	0.400	5.104
9	0.354	5.458
10	0.313	5.772
11	0.277	6.049
12	0.245	6.294
13	0.217	6.512
14	0.192	6.704
15	0.170	6.874
16	0.151	7.024
17	0.133	7.158
18	0.118	7.275
19	0.104	7.380
20	0.092	7.472
21	0.082	7.554
22	0.073	7.626
23	0.064	7.690
24	0.057	7.747
25	0.050	7.797
26	0.044	7.841
27	0.039	7.880
28	0.035	7.915
29	0.031	7.946
30	0.027	7.973

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 3% slower than general price levels.

Table -2

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = -2%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.945	0.945
2	0.844	1.790
3	0.754	2.543
4	0.673	3.216
5	0.601	3.817
6	0.536	4.353
7	0.479	4.832
8	0.428	5.260
9	0.382	5.642
10	0.341	5.983
11	0.304	6.287
12	0.272	6.559
13	0.243	6.802
14	0.217	7.018
15	0.193	7.212
16	0.173	7.385
17	0.154	7.539
18	0.137	7.676
19	0.123	7.799
20	0.110	7.909
21	0.098	8.007
22	0.088	8.095
23	0.078	8.173
24	0.070	8.243
25	0.062	8.305
26	0.056	8.360
27	0.050	8.410
28	0.044	8.454
29	0.040	8.494
30	0.035	8.529

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 2% slower than general price levels.

Table -1

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = -1%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.950	0.950
2	0.855	1.805
3	0.771	2.576
4	0.694	3.270
5	0.626	3.896
6	0.564	4.459
7	0.508	4.967
8	0.457	5.424
9	0.412	5.836
10	0.371	6.207
11	0.334	6.542
12	0.301	6.843
13	0.271	7.115
14	0.245	7.359
15	0.220	7.579
16	0.198	7.778
17	0.179	7.957
18	0.161	8.118
19	0.145	8.263
20	0.131	8.394
21	0.118	8.511
22	0.106	8.618
23	0.096	8.713
24	0.086	8.799
25	0.078	8.877
26	0.070	8.947
27	0.063	9.010
28	0.057	9.066
29	0.051	9.118
30	0.046	9.164

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 1% slower than general price levels.

Table 0

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 0%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.954	0.954
2	0.867	1.821
3	0.788	2.609
4	0.717	3.326
5	0.652	3.977
6	0.592	4.570
7	0.538	5.108
8	0.489	5.597
9	0.445	6.042
10	0.405	6.447
11	0.368	6.815
12	0.334	7.149
13	0.304	7.453
14	0.276	7.729
15	0.251	7.980
16	0.228	8.209
17	0.208	8.416
18	0.189	8.605
19	0.172	8.777
20	0.156	8.933
21	0.142	9.074
22	0.129	9.203
23	0.117	9.320
24	0.107	9.427
25	0.097	9.524
26	0.088	9.612
27	0.080	9.692
28	0.073	9.765
29	0.066	9.831
30	0.060	9.891

* These factors are to be applied to cost elements which are anticipated to escalate at the same rate as the general price level.

Table 1

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 1%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.959	0.959
2	0.880	1.839
3	0.808	2.647
4	0.742	3.389
5	0.681	4.070
6	0.626	4.695
7	0.574	5.270
8	0.527	5.797
9	0.484	6.281
10	0.445	6.726
11	0.408	7.134
12	0.375	7.509
13	0.344	7.853
14	0.316	8.169
15	0.290	8.459
16	0.266	8.726
17	0.245	8.970
18	0.225	9.195
19	0.206	9.401
20	0.189	9.590
21	0.174	9.764
22	0.160	9.924
23	0.147	10.070
24	0.135	10.205
25	0.124	10.328
26	0.113	10.442
27	0.104	10.546
28	0.096	10.642
29	0.088	10.730
30	0.081	10.810

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 1% faster than general price levels.

Table 2

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 2%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.963	0.963
2	0.893	1.856
3	0.828	2.684
4	0.768	3.452
5	0.712	4.165
6	[illegible]	4.825
7	[illegible]	5.437
8	[illegible]	6.005
9	[illegible]	6.531
10	[illegible]	7.020
11	[illegible]	7.478
12	[illegible]	7.892
13	[illegible]	8.281
14	[illegible]	8.642
15	[illegible]	8.977
16	[illegible]	9.287
17	[illegible]	9.575
18	[illegible]	9.842
19	[illegible]	10.089
20	[illegible]	10.319
21	[illegible]	10.531
22	[illegible]	10.729
23	[illegible]	10.911
24	[illegible]	11.081
25	[illegible]	11.238
26	0.146	11.384
27	0.135	11.519
28	0.125	11.645
29	0.116	11.761
30	0.108	11.869

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 2% faster than general price levels.

Table 3

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 3%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.968	0.968
2	0.906	1.874
3	0.849	2.723
4	0.795	3.517
5	0.744	4.261
6	0.697	4.958
7	0.652	5.610
8	0.611	6.221
9	0.572	6.793
10	0.536	7.329
11	0.501	7.830
12	0.470	8.300
13	0.440	8.739
14	0.412	9.151
15	0.386	9.536
16	0.361	9.897
17	0.338	10.235
18	0.316	10.552
19	0.296	10.848
20	0.277	11.126
21	0.260	11.386
22	0.243	11.629
23	0.228	11.857
24	0.213	12.070
25	0.200	12.270
26	0.187	12.457
27	0.175	12.632
28	0.164	12.796
29	0.154	12.950
30	0.144	13.093

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 3% faster than general price levels.

Table 4

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 4%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.972	0.972
2	0.919	1.892
3	0.869	2.761
4	0.822	3.583
5	0.777	4.360
6	0.735	5.095
7	0.695	5.789
8	0.657	6.446
9	0.621	7.067
10	0.587	7.654
11	0.555	8.209
12	0.525	8.734
13	0.496	9.230
14	0.469	9.699
15	0.443	10.142
16	0.419	10.561
17	0.396	10.958
18	0.375	11.333
19	0.354	11.687
20	0.335	12.022
21	0.317	12.339
22	0.299	12.638
23	0.283	12.921
24	0.268	13.189
25	0.253	13.442
26	0.239	13.681
27	0.226	13.908
28	0.214	14.121
29	0.202	14.324
30	0.191	14.515

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 4% faster than general price levels.

Table 5

PROJECT YEAR INFLATION [illegible] FACTORS

Differential Inflation Rate = 5%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.977	0.977
2	0.933	1.910
3	0.890	2.800
4	0.850	3.650
5	0.811	4.461
6	0.774	5.235
7	0.739	5.974
8	0.706	6.680
9	0.673	7.353
10	0.643	7.996
11	0.614	8.610
12	0.586	9.196
13	0.559	9.755
14	0.534	10.288
15	0.509	10.798
16	0.486	11.284
17	0.464	11.748
18	0.443	12.191
19	0.423	12.614
20	0.404	13.018
21	0.385	13.403
22	0.368	13.771
23	0.351	14.122
24	0.335	14.458
25	0.320	14.777
26	0.305	15.083
27	0.292	15.374
28	0.278	15.653
29	0.266	15.918
30	0.254	16.172

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 5% faster than general price levels.

Table 6

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 6%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.982	0.982
2	0.946	1.928
3	0.912	2.839
4	0.878	3.718
5	0.847	4.564
6	0.816	5.380
7	0.786	6.166
8	0.757	6.923
9	0.730	7.653
10	0.703	8.357
11	0.678	9.035
12	0.653	9.688
13	0.629	10.317
14	0.607	10.924
15	0.584	11.508
16	0.563	12.071
17	0.543	12.614
18	0.523	13.137
19	0.504	13.641
20	0.486	14.127
21	0.468	14.595
22	0.451	15.046
23	0.435	15.480
24	0.419	15.899
25	0.404	16.303
26	0.389	16.692
27	0.375	17.066
28	0.361	17.427
29	0.348	17.775
30	0.335	18.111

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 6% faster than general price levels.

Table 7

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 7%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.986	0.986
2	0.959	1.946
3	0.933	2.879
4	0.908	3.787
5	0.883	4.670
6	0.859	5.529
7	0.836	6.364
8	0.813	7.177
9	0.791	7.968
10	0.769	8.737
11	0.748	9.485
12	0.728	10.212
13	0.708	10.920
14	0.688	11.608
15	0.670	12.278
16	0.651	12.930
17	0.634	13.563
18	0.616	14.180
19	0.600	14.779
20	0.583	15.363
21	0.567	15.930
22	0.552	16.482
23	0.537	17.019
24	0.522	17.541
25	0.508	18.049
26	0.494	18.543
27	0.481	19.023
28	0.467	19.491
29	0.455	19.946
30	0.442	20.388

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 7% faster than general price levels.

Table 8

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 8%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.991	0.991
2	0.973	1.964
3	0.955	2.919
4	0.938	3.857
5	0.921	4.777
6	0.904	5.681
7	0.888	6.569
8	0.871	7.440
9	0.856	8.296
10	0.840	9.136
11	0.825	9.961
12	0.810	10.770
13	0.795	11.565
14	0.781	12.346
15	0.766	13.112
16	0.752	13.865
17	0.739	14.603
18	0.725	15.329
19	0.712	16.041
20	0.699	16.740
21	0.687	17.427
22	0.674	18.101
23	0.662	18.762
24	0.650	19.412
25	0 638	20.050
26	0.626	20.676
27	0.615	21.291
28	0.604	21.895
29	0.593	22.488
30	0.582	23.070

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 8% faster than general price levels.

Table 9

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 9%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	0.995	0.995
2	0.986	1.982
3	0.977	2.959
4	0.969	3.928
5	0.960	4.887
6	0.951	5.839
7	0.942	6.781
8	0.934	7.715
9	0.925	8.640
10	0.917	9.557
11	0.909	10.465
12	0.900	11.366
13	0.892	12.258
14	0.884	13.142
15	0.876	14.018
16	0.868	14.886
17	0.860	15.746
18	0.852	16.598
19	0.845	17.443
20	0.837	18.279
21	0.829	19.109
22	0.822	19.930
23	0.814	20.745
24	0.807	21.551
25	0.800	22.351
26	0.792	23.143
27	0.785	23.928
28	0.778	24.706
29	0.771	25.477
30	0.764	26.241

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 9% faster than general price levels.

Table 10

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 10%*
Discount Rate = 10%

Project Year	Single Amount	Cumulative Uniform Series
1	1.000	1.000
2	1.000	2.000
3	1.000	3.000
4	1.000	4.000
5	1.000	5.000
6	1.000	6.000
7	1.000	7.000
8	1.000	8.000
9	1.000	9.000
10	1.000	10.000
11	1.000	11.000
12	1.000	12.000
13	1.000	13.000
14	1.000	14.000
15	1.000	15.000
16	1.000	16.000
17	1.000	17.000
18	1.000	18.000
19	1.000	19.000
20	1.000	20.000
21	1.000	21.000
22	1.000	22.000
23	1.000	23.000
24	1.000	24.000
25	1.000	25.000
26	1.000	26.000
27	1.000	27.000
28	1.000	28.000
29	1.000	29.000
30	1.000	30.000

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 10% faster than general price levels.

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